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LIFE'S UNFOLDING

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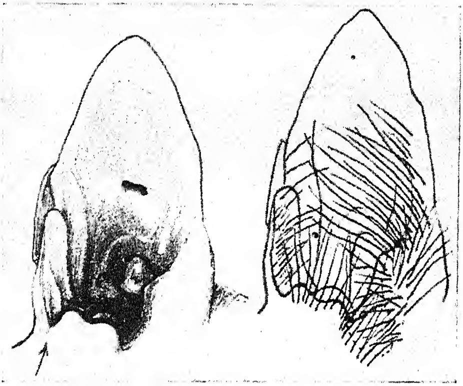
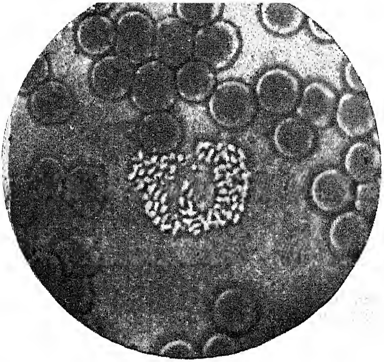


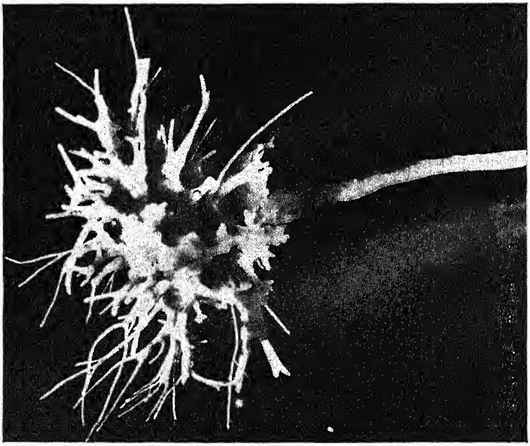
ENTRANCE OF THE CAT'S EAR.

Left: shaven to show the contours. Right: the palisade hairs across the entrance, which excite a rhythmic head-shake expelling any intruder. The act is reflex.

[*Frontispiece.*



Photograph of living blood, showing its cells; magnified about 900. The numerous disc-shaped cells are those containing the respiratory pigment. They are not actively motile, but are carried by the blood-stream. The single larger cell devoid of pigment moves actively, can attack invading germs, and from its likeness to a pond-amoeba is called amoeboid. It is granulated; the clearer central area in it is the nucleus.



Model, greatly magnified, of a large nerve-cell from the brain of a fish. Its bristling brush-like part is 'receptive' for messages from a distance; its single stem-like projection to the right is its nerve-fibre transmitting the messages to a muscle-like organ at a distance.

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LIFE'S UNFOLDING

BY

SIR CHARLES SHERRINGTON, O.M.

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INTRODUCTION

The Gifford Lectures delivered in Edinburgh during 1937 and 1938 have been published under the title of *Man on His Nature.** In the following pages three of the earlier chapters are reprinted. They deal with the specific theme of the unfolding of life from the microscopic cell, " an organized life-system centred upon itself," to the complex integrated organism of thinking man, and express the modern biological view of the fundamental problems of the relation between the living and the non-living and of the place of mind in evolution.

The trend of thought on these problems can be traced by comparing the general positions taken at various stages in the history of speculation. As, however, the science of a remote age is difficult to recapture and to assess in its own right apart from the society and sentiments in which it is entangled, more enlightenment is gained by taking a time and scene sufficiently akin to our own for us to share the viewpoints and to lay the science, along with its religious implications, conformably beside our own. The period chosen is the mid-Renaissance, which is regarded as the beginning of the modern age, and an outstanding representative is found in Jean Fernel, the author of a book *On Hidden Causes*, first printed in 1548. Fernel, whose life and teachings are outlined in the opening chapters of *Man on His Nature*, was physician to Henri II of France. Before turning

* *Man on His Nature*. By Sir Charles Sherrington, O.M. (Cambridge University Press.) 404 pp., 9 pp. index, and 12 plates; 21*s*.

actively to medicine he had been a lecturer in philosophy in his College within the University of Paris, had distinguished himself in mathematics, and had turned with enthusiasm to astronomy and geodesy. His treatise, written when he was entering on a great career in medicine, was a disquisition on man's place in Nature, and revealed him as a philosopher of liberal views and a reformer in medicine and its teaching. He was the earliest to draw together physiology, calling it for the first time by that name, and holding it to be the necessary introduction to scientific medicine.

The background of the book and of its author was on the one hand the humanistic revival—then in flood—and on the other hand religious strife, beginning, and not least in France, to use fire and sword. Of the latter, however, Fernel's book bears little outward mark. Fernel's inspiration had come from an aphorism of Hippocrates which had long teased his thought—the sentence asking " whether in disease there is not something supernatural? " The question came to Fernel across centuries beset with magic and miracle.

In the society around him the preternatural entered into every argument about health and disease, and about every exceptional undertaking in life. Astrology flourished among both the learned and the unlearned; Fernel himself embraced it for a period as part of medical wisdom. Following the teaching of Hippocrates and Galen, all disease was accounted for by the doctrine of the temperaments—the sanguine, the choleric, the phlegmatic, and the melancholic; health accompanied an approximate balance of the four, and illness resulted from a loss of balance.

Fernel was alone amid his confraternity in questioning

this universality of claim. "Misbalance of constitution is the illness," he wrote, "yet the cause is the practical point. There are causes we do not know." Here he was thinking not of preternatural, but of natural causes, even though they came from the stars. His endeavour was to be guided by natural truth; he was one of those to whom "the philosophy of Nature" made a strong appeal. At the same time he was, like the vast majority of his contemporaries, a convinced Christian. The world had for him two aspects, the natural and the religious, and as he was not one who could be content to hold his beliefs about Nature and his spiritual creed apart the one from the other, in separate chambers of his heart, he strove to effect a union between his scientific image of the world and his religious image of the world. His purpose commends him to us, and it would seem to have been shared by the cultured of his time, to judge by the large and lasting circle of the readers of his book.

It was natural, therefore, for Fernel to assume in the living body an incorporeal something which actuated it. This living principle, which came from the stars and informed all animate bodies with life, he called the soul. In plants the soul was nutritive and reproductive; in animals it was sentient as well as vegetative; in man the soul, besides being vegetative and sensitive, reasoned. In Fernel's conception these three souls were one soul. Nature had impressed upon him the continuity of all life; not only was the continuity of the animate traceable through all grades but there was continuity also between the animate and the inanimate. The transitions were always gradual, sometimes by imperceptibly small degrees, though not always, since there was a gap between man and all the rest. To step from man to the

rest was to pass from one order of things to something different enough to be another order wholly. Yet not wholly; man was alone and yet not alone, since there were myriads of things *partly* like him. As a physician, Fernel wondered whether these things might not exist just to be of use to man, providing remedies for all human ills. As a physician, also, he was sure that man, the greatest work of Nature, is within Nature. He treated mind itself as a theme within physiology; for him all the workings, mental and otherwise, which went on in "one" body were the acts of a spiritual incorporeal occupant of the body. Physiology and psychology were for him not separate sciences. In his book on Physiology there are chapters dealing with pure reason and the will, which are, in common with every other action of the body, treated as faculties of the incorporeal soul.

From this philosophy Fernel derived an attitude towards the causation of disease which was opposed to the professional orthodoxy of his time. Most disease, he held, was traceable to some Natural cause: "and happily so; for what derives from nature has assuredly somewhere in Nature its remedy and cure." While admitting that the preternatural also had its place in sickness, he urged that: "The physician must be on his guard however against supposing the preternatural where it is not." Some of the remedies supposedly of preternatural power were, he pointed out, merely creations of superstition, neither divine nor truly magical. The words "truly magical" reveal the world of superstition in which Fernel lived and from which he could not wholly escape. Against the darkness of traditional credulity he stood, a dignified figure, trying to observe

and trying to distinguish between the true and false. He was also a pathetic figure, because his means for distinguishing between them were so scant. He had his single-handed observation and his honest submission of tradition to the general test of reasonableness. These weapons were not wholly effective in overcoming the age-long prestige of the occult, but they did succeed in destroying Fernel's belief in astrology as a reliable agent of the physician. Himself a skilled astronomer, he was able to read the astrological soothsayings and check them against the facts observed by him among his patients. He began with every confidence in the stars but was gradually and completely disillusioned. The claim of astrology in medicine was subjected to the crucial test of whether it spoke truth of the sick-room; judged by that test he found it false and rejected it. How noteworthy an emancipation this was may be gauged by comparison with some of the still superstition-ridden beliefs of even two hundred years later.

Amid the quicksands of magic and superstition Fernel had one rock or foothold, largely of his own finding—the first-hand observation of fact. There was in him a scientific instinct, exceptional at that time. He was one of the few who, searching single-mindedly in the natural for the expected supernatural and gradually establishing that it was not there, had the honesty to say so. To them we owe the expulsion of the pseudo-preternatural from the world, which was a step towards making the freed world homogeneous. The preternatural gone, our world became more intelligible. Strange, extravagantly strange, as our world may appear, it is never a magic, a self-contradictory, world. Its facts, however opposed they may seem, have a perennial habit of ultimately

agreeing. This reconcilability of natural facts connotes that all Nature is a harmony, which includes man. If the fundamental substance of ourselves and of the universe is one, then, clearly, a harmony between them there must be. We and Nature are all one. True, this "self" of ours seems to each of us a something different from other Nature; yet it obviously belongs to the harmony, for it is that part of the harmony whence we feel that the harmony is.

Our insight into Nature is, we can say without exaggeration, of a different order from that allowed to our ancestors of Fernel's day. The world's horizon is new to the degree of offering a wholly new perspective. The half-gods are not only vanished, they are by nigh forgotten; matter for labels and a museum shelf. We have exchanged a monstrous world for one relatively sane; to-day man can go into the natural world without carrying the distortion of monstrosity with him. We can interrogate the natural world with a confidence drawn from riddance of misunderstanding no less than from extension of understanding. It is for us not to forget our escape from a long nightmare; it is for us to pursue our interrogation in the spirit to which Fernel, though unable to free himself wholly from the nightmare, strove always to be faithful.

C. S. S.

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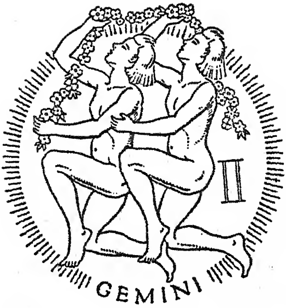


I

LIFE IN LITTLE

Recuerdo que una vez me pasé sobre el microscopio veinté horas seguidas, avizorando los gestos de un leucocito moroso, en sus laboriosos forcejecos para evadirse de un capilar sanguineo.

SANTIAGO RAMON-Y-CAJAL, *Recuerdos de mi Vida*, ed. 3, ii, 171.

(I remember that once I spent twenty hours continuously at the microscope watching the movements of a sluggish leucocyte in its laborious efforts to escape from a blood capillary.

Trans. by E. HOME CRAIGIE, Toronto, 1937.)

the imagination represented by the words " accidental play of molecules and atoms " (K. SAPPER, Philosophie des Organischen, 1928) *corresponds to nothing in Nature.*

KEITH W. MONSARRAT, *Human Understanding and its World*, p. 278.

1

WE were looking at the mid-sixteenth century. It was a time we can regard as in ways not a few the opening of our own. We were enquiring what the student of Nature then interpreted Life to be. One thing we noted was that he, facing Nature, regarded man, in fine, himself and ourselves, as Nature's chief object and her special care. In his view Nature centred upon man. Said briefly, and therefore inadequately, for Aristotle man was the social animal; for Fernel, physician of the sixteenth century, man was the animal with the immortal soul.

All mankind in one or other of different ways studies Nature. Every man does so perforce in order to live. But down the ages in the civilized community there has been one class of observer of Nature who has given himself to its study more intimately than have the rest. That is the physician. Every allowance made for the variety of human temperament, the upshot has been a view of Nature which arrives at being generic and can be called the physician's view. Broadly taken there has been one item of Nature which has held his interest more than any other: the body of man. It is study and preoccupation with the human body which largely determines the physician's view of Nature. Of all the works of Nature, said Galen, physician to the Stoic emperor, it is the human body which bears supreme testimony to the greatness of the heavenly power. Fifteen centuries later we find that sturdy old Pictavian and physician, Lussauld, of the court of the Grand Monarque, outraged by Descartes' thesis " that God formed the human body, the living frame of one of ourselves, out of no other than matter and without putting into it a soul, and in its heart just lit a low flameless fire like that which heats hay or

makes new wine bubble." * Where does Fernel stand in this succession?

Life was for Fernel a principle which was resident in the body. That principle was not all of a piece with the body. What the body did was the result of its activation by this principle inside it, its 'life.' This settled, certain other things flowed thence. Consequences without indeed observational proof. Considerations, however, derived from arguments of such force and so consistent with the revelations of religion as to be acceptable, although beyond actual observation. Of these were that the human principle of life entered the body at its due time from without, all in a moment, and that at that moment the individual became a separate existence from the maternal existence. This principle, or soul, came to the body from the stars or perhaps from the 'primum mobile' beyond the stars. Further, that at death this living principle—or at least a part of it, that part identified with rational mind—returned from the body to the celestial region whence it came.

This, judging by our type of his time, Jean Fernel, was an interpretation of man as creature which found some general acceptance among those who gave thought to such questions fifteen generations back. Fifteen generations seems, as history goes, a short series to look back across. Yet it may suffice to show how change is trending; seen across it Fernel's picture already bore its streaks of sunset and approaching end.

To ask the definition of life is to ask a something on which proverbially no satisfactory agreement obtains. Bichat described life as a result of forces counteracting death. That was no cynicism on his part; for our

* *Apologie pour les Médecins contre ceux qui les accusent de déférer trop à la Nature et de n'avoir point de Religion*, par le Sieur Lussauld, Conseiller et Médecin ordinaire du Roy, 12°, ii, 53. Paris. Damien Foucault, 1663. Contemporary references to the book are made in Guy Patin's *Lettres*, e.g. Lettre 816. The *Apologie* was reprinted, with extensive annotations, by P. J. Amoreux, in 1816 at Montpellier and Paris.

purpose, however, it is better perhaps to take some particular form of life as an example of life, and try in brief to describe it and see what it amounts to.

There is a little aggregate of atoms and molecules such as the world we call lifeless nowhere contains. It is confined to living things; many of these it enters into as a unit, and builds up. It is a unit with individuality. Taken singly it behaves as an entire life. In many cases it does constitute of itself an entire life, although but a pin's point in size. The individual where massive consists, for the longer part of its duration, of many of these tiny units massed together. But its life story still begins with just a single one of them.

The microscope, when in the seventeenth century it came, had this unit, so to say, waiting for discovery. Our physician-philosopher, Fernel, had written not a century earlier that divide and subdivide a bit of gland, skin or muscle or other part of the body as far as you will, it still remains gland, skin, or muscle, etc. In short, minute muscle was traceable simply back into minuter muscle. The microscope would have undeceived him about this. It would have shown him how, at a little beyond the limit of unaided eyesight, gland and muscle and indeed all parts of the body resolved themselves into little units of structure which, though characteristic for each, were all of them fundamentally of the same type. To these units Robert Hooke of the Royal Society, an early observer with the microscope, gave the name 'cells.' Practically the whole of all that part of the animate world which is individually visible to the unaided eye is built up of cells.

Just as Fernel, through no fault of his own, by no amount of looking could reach the cellular analysis of living things, so too he had no chemical analysis to turn to. Chemistry as we know it was not as yet. There were no chemical elements. Fernel's elements were the four of classical antiquity: earth, air, fire and water. As he said regretfully, these are not to be recognized in the

body by observation. They are known only by 'excogitation.'

The microscope had in store yet another surprise about living Nature. A class of animate being had remained till then unknown, because it was individually too small for the unaided sight. The microscope revealed a world of living things so small that without the microscope man cannot see them. It was an astonishment to the early observers that the living principle could be immanent within individuals so small, specks unseeable by the naked eye. Our naïve imagination, it appears, had never entertained the possibility. Buffon, the naturalist, and others were for a time and in a manner scandalized by the news. Man's sense of proportion was outraged. It seemed an indignity to the human form. That a drop of water should contain thousands of individual lives raised a feeling that such a circumstance was derogatory to life itself, and to man. But the fact established itself. These microscopic forms swam, darted, fed, were shaped incredibly, and each was a concrete individual life. In the seventeenth century they came as a revelation comparable with the expansion of the nine Ptolemaic spheres to the immensities of the Galileo-Newton universe. The conception of creation was enlarged in both directions. In one a universe of unimagined vastness, and in the other a fairyland of created beings, tiny and various beyond imagination, in a single drop of fluid. It was recognized that 'life' could exist as a speck. The cell exemplified that. Reviewing the pioneer work of the microscope in the seventeenth century Charles Singer truly says, "Variety and complexity now begin to overawe the naturalist." * And lately we have come to know that there are individual lives even more minute than the most powerful microscope shall show us. So the revelation of tenuity continues. But these latter are not 'cells.'

To-day the contemplation of animate Nature is more

* *Short History of Biology*, p. 171.

'historical' in view than in those times. Geology has made it so; evolution has made it so; astronomy itself has contributed to make it so. A thought which arises with regard to the cell to-day is that in the history of the planet at some time, after life had made its appearance under the stratosphere, there must have supervened a period when that organized microscopic structure, which proved the seed of so much significant life and is the cell, arose from still simpler life. It is far too complex to have arisen full-fledged as such. Further, the doings of this little individual life must somewhere and at some time have acquired the property of providing for its progeny to cohere in co-operative organization. Lesser lives thus have co-operated to make larger lives. Man is one of the latest of these latter.

Each of us still at the outset of his or her individual life story is microscopic and one sole cell. By that cell's multiplication, and by its descendants' coherence, each of us attains his or her final form and size. Each at every stage of that astonishing 'becoming' is never any less than a self-centred individual. This is a breakaway from Fernel's view. For him the unborn infant was a mere part of the parent until the soul entered on the fortieth day. For present knowledge the offspring has from outset its individuality. It is never at any time truly a part of the mother. The mother's body prepares a nest for it. Each month the mother's body prepares such a nest against eventuality. The young creature, separate individuality as it is, finds the newly prepared nest ready for it, and occupies it. Ensconced there it thrusts thence suckers into the maternal tissue, and draws from the circulation of the mother nutriment, and in effect breathes through its mother's circulation. The embryo is, however, never any part of the mother, never at any time at all a part of the maternal life, as pious doctrine had supposed. The embryo's life and the mother's life at no time are confluent or commingled. The new life is on its own though it lives as a parasite on

the old, a benign parasite, doing the mother no harm and destined at term to set the hostess free. Then the old nest is shed with it, having served its purpose.

The embryo, even when its cells are but two or three, is a self-centred co-operative society which is familial and a unity—an organized family of cells, with corporate individuality. This character of being an individual seems, as we look upon Nature, a feature peculiarly stressed in what is living. Physics perforce has dealt mostly with ' crowds,' but biology has before it commonly the individual. When Aristotle, in living Nature, had reached the *infima species*, he had not reached, as so long was thought, a scientific end-point; rather he had reached a starting-point whence a new scientific problem opened and could be entered on. Aristotle never forgot the capital importance of the individual. Not that Science to-day clings to any notion that there can be an ' end-problem ' in the sense of a reaching of finality. The scientific journey has no end. It has only halting places—points at which the traveller can look round and survey. An end-problem exists only in the sense of a previous problem which carries up to the starting-point of another. Thus, on the discovery of evolution, immediately there rose a next question: " What is variation?"

The human individual is an organized single family of cells, a family so integrated as to have not merely corporate unity but a unique corporate personality. The doings of this cell-assembly are—itself supposes, society allows, and the Law decrees—those of a being which is one, a unity. Yet each of its constituent cells is a life centred in itself, managing itself, feeding and breathing for itself, separately born and destined separately to die. Further, it is a life helped by, and in its turn helping, the whole assembly, which latter is the corporate individual; such co-operation is one key to what we may call the incorporation, or the integration, of the individual.

To declare that, of the component cells which go to

make us up, each one is an individual self-centred life, is no mere phrase. It is not a mere convenience for descriptive purposes. The cell as a component of the body is not only a visibly demarcated unit but a unit-life centred on itself. It leads its own life. All those doings which our customary scientific rules ask a living thing to do it does. In the life of the organism of which it is a part it is a unit-life dynamically and structurally. Its shape and visible parts, commonly called structure, are indeed in fact as dynamic as any of its other features. Boundary membranes, etc., are to appearance more stable, but they are none the less steady states or moving equilibria, and as 'living' as the rest. The cell is a polyphasic system whose total average dynamic equilibrium rests on energy-exchange between its parts and between them and its surround, an energy-exchange organized so as to centre on itself. Cells in some cases are joined to each other and might seem therefore not to be separate lives. The microscope may not be able to trace the separation between them. That is so with many nervous cells. They were long thought to be a continuum and not separate. But experiment can discover at once that, although they meet, there is no union of one with the other. Injury or disease, separating the cell-component of the junction from the rest of its cell, disintegrates that component of the junction and shows, as by a cut with a knife, the point where the two separate cells met, and that they met there without a trace of union.

Each cell is an organized life-system centred upon itself. We cannot say more *qua* energy-system of the sum-total individual of any of us. And in chemical nature also the cell is the same as in chemical nature we are, for there is nothing in us except cells. The cell is a unit-life, and our life, which in its turn is a unitary life consists utterly of the cell-lives.

To say that each cell is a unit-life is to say that each cell also is a whole. The cell is not a polyphasic chemico-

physical system merely. Many a mere drop of complex jelly could be that. The cell is a polyphasic chemico-physical system which is integratively organized. Hence there comes about that it can answer to what is described as 'life.'

To this balanced exchange with the surround, an exchange which centres on the autonomy of the cell's life, there is essential a certain plasticity which is native to every cell. Adjustment to the nature of the surround is a condition of its life. Where, as in the many-celled individual, the cell's surround consists of other cells, each cell's autonomy is influenced by the cells in its proximity. That the cell is thus influenced by other cells and co-ordinated with and modified by them must not be mistaken for its no longer having a self-centred life. Its very specialization which results is a sign of its autonomy. To suppose it has become merely a part of some other life than its own is to forget facts. The component cells of the body assert the fact of their individual autonomy of living in many ways. They remain unit-lives. Take for instance the highly specialized static-looking nerve-fibre. It is 'cellularly' (*Frontispiece*) a slender branch from a nerve-cell 'miles away.' Let it be severed, and the reaction declares at once that a cell's autonomy has been injured. The fibre severed from its cell dies, and the nerve-cell miles away, whose fibre it was, thrusts forth a new fibre to replace the old. Again, at a seat of inflammation the tissue-cells unfix themselves, move about, and resettle down in new shapes as part of the repair. Or, again, when that disaster cancer happens. The cancer-cells which themselves derive from cells of the breast, liver or what not, become active and independent to the degree of resembling parasitic invaders of the body. Watched in a motion-film, where life's movements are speeded up perhaps a 100 times, they seem almost audible as they jostle past and push through the 'quieter' normal cells. They seem possessed by a kind of senseless frenzy, senseless because, although imbued with prodigious

and reproductive energy, like that of the cells of an embryo, they and what they build are planless. In the healthy body everything is planful. The many-celled organism such as each of us is, was one cell at beginning, and when it has become many-celled the behaviour of the constituent cells shows that each one of them like the parent-cell is still an autonomous unit-life. But the behaviour of the individual cell in the body is restrained by influences of its fellow-cells. The desistance from further growth beyond the adult stage is partly traceable to this. There is a scrap of tissue from an embryo-chick transferred to artificial culture thirty years ago which is growing vigorously as ever now to-day; if left within its chick it would have ceased years since.

Some of our cells, although they are part and parcel of us, have not even fixed coherence with our 'rest.' Such cells are called 'free.' The original cell which started the whole body was free, as are all those of that particular kind. And others too are free. The cells of our blood are as free as fish in a stream. They are in the stream of the blood. Some of them resemble in structure and ways so closely the little free-swimming amoeba of the pond as to be called amoeboid (*Frontispiece*). The pond amoeba crawls about, catches and digests particles picked up in the pond. So the amoeboid cells inhabiting my blood and lymph crawl about over and through the membranes limiting the fluid channels in the body. They catch and digest particles. Should I get a wound they contribute to its healing. They give it a chance to mend, by eating and digesting bacteria which poison it, and by feeding on the dead cells which the wound-injury has killed. They are themselves unit-lives, and yet in respect to my life as a whole they are components in that corporate life.

The human situation to-day as regards the conception of life is therefore not where it stood with our sixteenth-century philosopher-physician. Simple visual magnification with enlarging lenses brought about a change which

would have startled Jean Fernel. His life-principle, which in virtue of its simplicity as a unitary whole was imperishable,* is faced with having to resolve itself into millions of local principles, operating each of them one tiny speck of material. There is a little book written in Henry VIII's time by one who was at once a physician and a divine, Dr Peter D'Acquetus, a chaplain to the Bishop of Ely. In it are set down a number of questions about which he is curious and has consulted learned friends. One of these questions is whether the hairs of the head grow after death. Meaning by death the flight of the soul from the body he has no answer to what seems to him incredible. Nor would he have understood if he had been told the hair still goes on living for some time after heart and breath have ceased. Perhaps some physician of his time would have answered him that Aristotle regarded the *anima* as in not a few instances divisible, and that it might linger longer in some parts than in others. But he might well have thought that savoured too much of Averrhoes, the infidel commentator, to insert it in his book. Fernel's faculties of the psyche have multiplied so as to be numberless. To this he might probably be led to say, " the immanent spark of life pervades every speck of material of the body." What would have given him pause would have been this divisibility of the indivisible psyche.

The biological problem of life fell asunder, in so far, into two subdivisions, the life of the constituent cell and the life of the total constituted organism. The former subdivision oddly is called general physiology, the latter special physiology. A significant gloss upon that is that the total organism begins as one cell. That does not mean that the problem is in the beginning a general one and becomes special. It is special from the very start, as well as general; and it remains general to the very end as well as special. The human starting-point even at outset, when but one single fertilized cell, is already not

* *De Nat. Parte Med.* v, 18.

general but 'human.' It is as human at the beginning as at any later time, even if there comes later, in the concrete case, the wearing a stove-pipe hat.

The life of a cell, what conception may we form of it? A speck of material which is said to 'live,' while the vast majority of specks of material are said to be lifeless. Has it some particular element of matter in it which those other specks have not? No; that is not the key. The elements of matter—and we are thinking of them now not in Fernel's sense but in that stricter one of the chemical 'element' of to-day—in the living cell are among the very commonest of those spread broadcast in material which does not 'live,' in soil, rock, air and water. Perhaps what strikes us most in the list of chemical elements which make us up, is the negative fact that the majority of elements are left out, and all the rarer ones. But in the speck that lives the common elements are differently compounded. For one thing they compose a tiny droplet of granular jelly. That is, it is not matter in any one single pure phase, solid, fluid, or gaseous; it is a mixture of all these. That is partly phrased by calling it colloid.

A good many years ago with the recognition that this jelly was the 'physical basis of life' it was christened 'protoplasm.' The name is less heard now than formerly. It serves to recall that the living material of the cell was then thought of as one definite specific compound. It might perhaps better have been called *X* as an unknown quantity. But that would have been less attractive and less intriguing. The name stood for a something, a compound substance, which as a chemical entity was a scene of living behaviour. It was thought of as broadly presenting two types of action, one a building up and one a breaking down. To call it protoplasm helped to substantialize it. As to its chemistry and what that precisely was, those were points left to a future admittedly far off. To attack it by chemical methods had, at that time, to face the paradox that such methods at once 'killed' it. The protoplasm was then no longer proto-

plasm, because by definition protoplasm was alive. To attempt the chemistry of life at its seat seemed therefore like asking to handle the rainbow's end. It was an entity but a will-o'-the-wisp. The spell of Galen was in fact over life still, in act though not in name.

To this phase there came a change. Before many years the organic chemist and the physical chemist entered biology. Their experience hitherto had been with crystalline stuffs. Perhaps they had not so often as had the rank-and-file biologist lingered over the microscope and followed, as had he, the mysterious dance of the nuclear segments about the astered spindle in the living cell. Perhaps they would not have cared if they had. However that may be, attacking life they did not hesitate to grind into unrecognizable fragments the living cell for obtaining from it what might be inside it. To many biologists this seemed a Philistine procedure. But it was an audacity which reaped a great harvest of new knowledge. Their mush of unrecognizably disintegrated cells, obtained by freezings, mincings, crushings, grindings, squeezings, yielded to chemical analysis secret after secret of cell-life. Protoplasm, or *X* (which of either we please to call it), became as entity a thing of the past. The cell was tenanted not by one thing but by many things, whole systems of things. It amounted to a little world of things.

Microscopic it is, but large as compared with some other structures which individually live—for instance, the bacterial spore, and the lately recognized 'virus,' smaller still. It is, of course, vastly larger than is any molecule. It is often itself a manufacturer of some of the very largest molecules, but when so they all comfortably house within it. There would be room on the surface of one cell for some hundreds of millions of the great rod-shaped or skein-shaped protein molecules, bristling with chemical receivers. Again, compared with those units, whether particles or waves, into which modern physics resolves matter, the little cell is a stupen-

dous aggregate. Its content of these rushing whirling electrical charges, some of them spinning many millions of times a second, is beyond practical enumeration. We remember the pains our sixteenth-century physician was at to show that the principle of life is simple, an indivisible unity. Having no parts, being structureless, and therefore unable to come to pieces, it was immortal. From that the conception we are approaching seems to retreat farther and farther.

Essential for any conception of the cell is that it is no static system. It is a material system and that to-day is to say an energy-system. Our conceptions of it fail if not dynamic. It is a scene of energy-cycles, suites of oxidation and reduction, concatenated ferment-actions. It is like a magic hive the walls of whose chambered spongework are shifting veils of ordered molecules, and rend and renew as operations rise and cease. A world of surfaces and streams. We seem to watch battalions of specific catalysts, like Maxwell's 'demons,' lined up, each waiting, stop-watch in hand, for its moment to play the part assigned to it, a step in one or other great thousand-linked chain process. Yet each and every step is understandable chemistry. The cell has proved to be a perfect swarm of catalysts, or of trains of catalysts, each a link in a serial suite of chemical action.

An aspect of the cell which helps towards understanding it, both as chemistry and as life, is that although it is fluid and watery, most of it is not what is called a true solution. Judged by present-day lights a drop of true solution, of homogeneous liquid, could not in our ordinary sense of the word 'live.' It is too remote from 'organization.' In the cell there are heterogeneous solutions. The great molecules of protein and aggregated particles are suspended not dissolved. A surface is a field for chemical and physical action. The interior of a pure solution has not in that sense surfaces. But the aggregate of surface in these foamy colloids which are in the cell mounts up to something large. The 'internal

surface' of the cell is enormous. It offers a vast field for chemical action. The cell gives chemical results which in the chemist's laboratory are to be obtained only by temperatures and pressures far in excess of those the living body has at its command. Yet in the cell these results are obtained without those temperatures and pressures. Part of the secret of life is the immense internal surface of the cell.

In the spongework of the cell foci coexist for different operations, so that a hundred, or a thousand different processes go forward at the same time within its confines. The foci wax and wane as they are wanted. That the cell's field is a colloidal field makes explicable much which would otherwise not be so. But the cell is much more than merely a droplet of colloidal jelly. The processes going forward in it are co-operatively harmonized. The total system is organized. The various catalysts work as co-ordinately as though each had its own compartment in the honeycomb and its own turn and time. In this great company, along with the stop-watches, run dials telling how confrères and their substrates are getting on, so that at zero time each takes its turn. Let that catastrophe befall which is death, and these catalysts become a disorderly mob and pull the very fabric of the cell to pieces. Whereas in life as well as pulling down they build, and build to a plan.

These and many considerations force on us the conception of the cell as 'organization.' One of its aspects must be definite spatial arrangement. There is in every cell a visible kernel called the nucleus. It is directive; a central nest of ferments. Remove it from the cell and the cell's rest gets out of gear and dies. There is too the cell's outer surface. It would seem the proteins there connect with those of the nucleus by protein threads. Proteins, which are the very basis of the cell, provide it with a sort of quasi-skeleton. They can make semi-rigid rods; they can spread film-like, in touch with the fatty films of the cell's outward skin. The cell thus gets a

subvisible skeleton in accord with the scheme of its internal directive organization. The cell is of course in constant commerce with the chemical world around it. In the case of a cell inside the body packed in among the others this chemical world around it is a very special chemical world. We can regard the cell's outward surface as a mosaic of a million chemical poles attracting to it and retaining what can dovetail with their pattern and enter the electrical construction. Its outer surface also leaks like a sieve allowing molecules to be expelled and drained away when done with.

The cell is an organized factory conducting manifold chemical processes. It hydrolyses, it pulls to pieces, it excretes. Further, it constructs. From bacterium to tree, from animalcule to man, proteins, broadly taken, are the stones of which the house of life is built. The cell makes its own proteins. It remakes them for itself from others supplied to it. 'Life' is a maker of proteins.

The red pigment of our blood does exquisite things. The 'flame' of life is scarcely metaphor. Our blood pigment uses the circumstance that iron is a metal which plays fast and loose with oxygen. Iron notoriously easily oxidizes and deoxidizes. Our red pigment owes its colour to iron. It picks up oxygen from the air at the bottom of the lungs and travels with it and distributes it to all the several organs of the body. This taking and giving of oxygen by the iron-containing pigment is managed by minute differences of oxygen pressure. A few millimetres more oxygen pressure in the lungs drives the oxygen there into the pigment in the blood; a few millimetres less in the other organs allows the oxygen to be sucked by them from the pigment in the blood. For this to work successfully the tie by which the pigment holds the oxygen must be weak, and the physical constants required of the pigment have to be extremely true to standard. The required precision is meticulously met. In different animal species the physical constants differ just enough to fit in each species that species' peculiar

needs. Thus this pigment makes its specific contribution to life. It is a superlative oxygen-carrier for the purpose. It is not too much to say that it has rendered possible the type of life which is ours, and much other life as well. Each of us produces it daily in quantity sufficient to make good an equal quantity decomposed. The manufacturing of it by the animal body seems to have come about perhaps some hundred million years ago. The breed of cells (*Frontispiece*) which 'invented' it have never in all that time lost their trick. The evolutionary argument tells us that cell-chemistry has 'invented' it not once but several times. Cells of widely unrelated ancestry are producing it to-day; their ancestries must have separately invented it. Though these many living cells construct it, its construction lies beyond the skill and means of even the latest chemical science. Very complex, it is a miracle of efficiency for what it does. If it be claimed that animal and man are marvellously designed to meet the circumstances of Nature and that this pigment and its 'invention' bear tribute to the purpose and knowledge of that Design, this might seem indeed to offer a text in illustration. But collateral fact submits a curious gloss on that text.

A familiar chemical process is that which is called combustion. It is one of the chemical processes which man induces and employs on an ever-increasing scale in his demand from Nature for heat and power. It presents two forms; complete combustion where oxygen supply is in excess; incomplete combustion where oxygen is insufficient. Incomplete combustion produces carbon monoxide gas. Our blood-pigment reacting so beneficently with oxygen reacts also with carbon monoxide. Its chemical tie with carbon monoxide is stronger than with oxygen itself. If in the air we breathe there is carbon monoxide as well as oxygen our blood-pigment takes the monoxide. But whereas our body, for instance our brain, cannot live five minutes without taking oxygen, carbon monoxide is of no use to it. If our blood brings us carbon monoxide instead of oxygen we die of asphyxia,

'suffocation.' "Carbon monoxide is the cause of more deaths than those due to all the other gases. As an industrial poison it is second only to the worst"; so writes Dr Yandell Henderson, a leading authority on the matter. By reason of the chemical affinity between it and our blood-pigment, carbon monoxide "becomes a prime enemy of all red-blood creatures. The use of fire was man's first successful step in controlling the forces of Nature to his needs; but it brought with it the hazard of asphyxia," because of our blood-pigment. Claude Bernard first demonstrated this chemical predilection of our blood-pigment for carbon monoxide. It is to-day a gas which not only every hearth but every motor-car exhales. Our blood-pigment can be a fatal danger to us.

Part of the story of the development of life from our planet's side is its key-use of oxygen. And in due course in that story came the construction of this subtle pigment, which decisively increases life's access to the planet's oxygen. With it life opened a new vista of possibilities to itself. How it achieved its new instrument has not been traced. It is, we saw, a chemical means. If we project our human self into the problem of devising it, how should we proceed? Our purpose we should have and, such as they are, our knowledge and our reason. As to our device to meet what was required, reason would enquire into how the pigment acted. Reason would thus find the device deadly under certain allied situations. Would reason then resort to the device? Was then Nature's method mere trial and error, hitting off an *ad hoc* means which met part of the situation and introduced new dangers of its own? Our Fernel might interject, "the choice may have been this device or nothing." If so, we are back at Lucretius: matter is stronger than Olympus.

We are wont to figure the cell predominantly as structure. But our conception of it will be then even more inadequate than it need be, if we forget for a moment

that it is a moving structure, a dynamic equilibrium. It is a moving system so constituted as to establish itself and maintain itself for a time—a time which is very brief as compared with the persistence of many inanimate things. From and to the world around, it takes and gives energy. It is an eddy in a stream of energy. It has the power of throwing off from itself other eddies specifically like itself. In that way, though its personal eddy is brief, its specific eddy as a species lasts immensely longer. But that eddy has inherent in it tendencies toward change, so that, where we are able to look back far enough, we find great numbers of its specific forms have vanished, and a multitude of modifications taken their places. These too are all on their way to change. What the change will be in our own case is not without interest for us. But it remains at present largely beyond our forecasting. If we could forecast it better perhaps we might, to some extent, control it with a policy in view.

Returning to the definition of life, let us hear a gifted biochemist of to-day define life from his standpoint. " Biologists find," says Dr Needham, " their work is only possible if they define life as a dynamic equilibrium in a polyphasic system consisting of proteins, fats, carbohydrates, sterols, lipoids, cycloses and water." These terms are somewhat technical. The statement is in fact admirably lucid and comprehensive. It says a physical system made of certain chemical substances exhibits all that biochemistry discovers in life.

It is a delicate system. That is to say, if we regard it as a stream of movement which has to fulfil a particular pattern in order to maintain itself, then it is, relatively to the fields of movement in matter which we do not call living, more liable than many to be irretrievably disarranged and so fail to maintain itself. To be thus irretrievably disarranged is, if physics and chemistry admitted the word, to die.

In brief, it is an energy-system whose energy is turned to maintaining itself; for instance by (1) nutrition, that

is replenishing the system with more energy in suitable kind; (2) growth, that is, extending the system; (3) excretion, that is, separating from the system energy no longer suitable in pattern; (4) mass-movements of its parts, an activity which is intrinsically developed, such as locomotion, feeding and so on; (5) reproduction, that is, generating a new system independent of itself, a young individual potentially at least of its own kind. To behave in this way is in common and convenient phrase to manifest 'life.' It involves dependence on its surround for energy. It is a conception unthinkable apart from its surround. It is so locked into its surround that to extract it thence is to break it in all directions. It means a system ceaselessly taking energy from the surround, and shedding energy back thither. But what is shed would not do again as such for replenishing the living system. Life would mean therefore an ultimate exhaustion of the surround in regard to the energy which can support life were it not that life itself, taken in the sum, secures itself against that terrestrial impasse. Not uninteresting to compare with this is Fernel's argument that were matter not imperishable life would by now have used all of it up.* That is a remark on a scale quite unusual in Fernel's time.

There are a great variety of these energy-systems conveniently spoken of as alive. Some of them contain, making it chemically for themselves, an organic compound more complex, and, broadly taken, of even wider import, than the blood-pigment just spoken of. It is a compound which, so to say, traps a certain fraction of the energy reaching our planet from the sun. With this solar energy it constructs chemical compounds whose energy-store is of a kind that living systems of almost every sort can make use of. Our sixteenth-century physician-philosopher, holding to what tradition had long said and sung, was right in his veneration of the sun's influence, although he could not then know that the

* *Dialog.* i, 1.

sun's light holds the key to the green plant, and the green plant the key to life, animal and human.

It might seem that Fernel's insistence on the importance of the sun's ray to life, forecast in some measure what is known to-day. "Consider," he says, "the excellence of the sun, prime prince and controller of the world, favouring and forwarding every life that is. By its chastened heat it supports all living things in their doing what they do." The sun's heat he held to be not the same as elemental heat, the cardinal quality. It was a vital, a vivifying heat, in a sense which 'heat,' the cardinal element, was not. May we suppose from such a passage that, allowing for its general terms, and accepting it as somewhat figurative, our physician-philosopher, writing in the strain of much which had fallen from older centuries, has a conception of life not greatly different, broadly taken, from ours of to-day? To suppose so would be to mistake him.

For him a specific principle, life, was within each living thing and made it alive. That principle was a something from the sun. Why the lifeless did not live was because that principle was wanting to it.

To-day in both respects our thought is different. Instead of a specific principle which is life, life is an example of the way in which an energy-system in its give and take with the energy-system around it can continue to maintain itself for a period as a self-centred, so to say, self-balanced unity. Perhaps the most striking feature of it is that it acts as though it 'desired' to maintain itself. But we do not say of the spinning of a heavy top which resists being upset that it 'desires' to go on spinning. The very constitution of the living-system may compel it to increase; thus a self-fermenting protein-system, granted its conditions, *must* increase. Broadly taken however there is in 'living' nothing fundamentally other than is going forward in all the various grades of energy-systems which we know, though in some less rapidly and less balancedly than in others. Whether

atom, molecule, colloidal complex or what not, whether virus or cell or plant or animal compounded of cells, each is a system of motion in commerce with its surround, and there is dynamic reaction between it and the surround. The behaviour of the living body is an example of this, and we call it 'living.' The behaviour of the atom is an example of this and we do not call it 'living.' The behaviour of those newly discovered so-called 'viruses' is an example of this and there is hesitation whether or not to call it 'living.' There is between them all no essential difference.

The difference is one not of ultimate nature but of scheme and degree of complexity, nothing more. The elemental parts and elemental patterns are not novel. The atoms and subatoms are among Earth's commonest. 'Living' becomes a name for certain complexes of them, arrangements of which it may be said that they are organized integratively—i.e., to form a solidarity, an individual. Hence we do not speak of 'life' in association with absolute simplicity of organization; never with mere homogeneity of structure. It requires a heterogeneity which permits integration of its complex even if that latter be but a single cell. Thus, when the skill of Robert Chambers extracts the nucleus of a cell, the cell, bereft of that little organ, 'dies.' When its integrated coherence ceases, as sooner or later it will, it falls asunder into parts which are simpler and do not form a solidarity; and that is called 'death.' Fernel if he agreed to this way of thinking would still add "but you omit the 'cause'; the cause is withdrawal of the 'principle of life.'" Yet an energy-system which we call 'alive' does not radically depart from energy-systems which we do not call 'alive.' Both are chemical. Moreover the naturalist can point to a number of systems which fall into series between the 'living' and the 'lifeless,' thus the new 'viruses' dubitably better called alive or not alive. Life as a distinction between physico-chemical systems is a convention; convenient but not scientific.

The law of the land defines life; it must for social convenience do so; but it does so after the manner of framing rules for a game, as: "the ball is dead when beyond the white line." Chemistry and physics refuse to define life; they eschew the word. How would Fernel have looked at the life of a cell, had the cell as such been known to him? His principle of life in the whole body was we remember single and indivisible; it was although *in* the body not *of* it. He would have seen his global principle fall apart—in man into 15 billions of unit principles, each of which lives. The body's 'life-principle' has become particulate even as the body's matter is particulate, its particles which are said to live being called 'cells.'

Each such cell has its 'faculties' as Fernel had described in his paradigm of the 'life-principle.' Each has its *facultas attractrix*, its *facultas altrix*, its *facultas genetrix*, etc., and the microscope displays its faculties of moving, of ingesting, of excreting and secreting, and it has even that other faculty, new since Fernel's time, the faculty of breathing. Fernel in fact would feel convinced that this speck, the cell, has 'life' in it. For instance a speck-sized sample of them taken from a chick-heart thirty years ago and subcultured is still growing fast as ever!

Nor, accepting, if we do, the concept 'life-principle,' does the scale of the particulate life reach its limit at the smallness of a body cell. The bacterial spore, and the 'virus particle' are far smaller than the body cell; they yet display in Fernel's term the 'faculties' of life, assimilation, secretion, growth, reproduction, and the rest.

These faculties are however processes which examination resolves wholly into chemistry and physics. Chemistry and physics find them not separable from the rest of chemistry and physics. What we call by convention 'life' is then chemico-physical. Why not, then, say of other energy-systems than that of the 'cell' or of the body *in toto* that they have life? Why not say so of

the rock as well as of the tree? Why not of the component molecules of the cell as well as of the cell itself? There is indeed no good ground for speaking of these as living, those as not-living. When Professor Blackett speaks of the mean life of the mesotron particle and the Insurance Office speaks of the mean life of ourselves his particle's behaviour gives him no less right to do so than does ours the Insurance Office. Each is an energy-transaction which at some time ceases to be what it was.

If a definition has to exclude as well as to include, it must lean on a logical boundary of what it defines; the term life has no such boundary from lifeless. Fernel seeing man, his type of the inseparable unity of the 'life-principle,' disrupted into billions of microscopic lives may well ask to be shown, not only that these component unit-lives are demonstrable as 'lives,' but that this mass-life of the body and its organs is built up from them. He would learn that the study of physiology now commonly proceeds on that assumption and never finds it fail. He would be shown this great organ or that separated from the body and removed to an incubator and perfused with a warm nutrient fluid, and still as an aggregate of cells continuing to pursue its own organic life, and doing so for days on end. The heart continuing to beat; the pancreas to secrete insulin; the thyroid gland to secrete iodine, and to respond, by secreting more iodine, to a thyrotropic hormone added to the perfusion-fluid, as would the human being. The synthesis is thus offered him as well as the analysis. He is faced by his cardinal humour, the blood, instead of being an ebb-and-flow of fire drawn from the stars, being a nutrient fluid perfusing the body at large; and the heart, his regenerating alembic for the supra-stellar fire, being a force pump driving the perfusion-fluid round. The perfusion-fluid itself is chemical nutriment for all the cells of body, supporting their energy-needs. They are indeed the myriad lives into which the one and indivisible global 'principle of life' has by progress of knowledge been disrupted.

The thought might rise unbidden to Fernel, that instead of an occult 'principle of life' superadded *in toto* to the total body, it were simpler to suppose a population of minute systems each doing its bit of living for itself. Further, for these systems, since physics and chemistry are adequate to what each of them does, to omit the occult principle altogether as a superfluity. Then for each the circumlocution that it has life *in* it becomes unnecessary; it could be simply said of it, it 'lives.' The occult life-principle is thus, after the plan of Occam, dismissed as a 'superfluous cause.' But no, the idea of matter working itself seems to have been foreign to Fernel and his time. Disciple of Aristotle though he was there is nothing to show that he ever took Aristotle's point that matter might work itself.

The word 'life' still remains useful; a convenient, though not exact, term for all that exhibits the 'faculties' regarded as characteristic of 'life.' The total life is seen as an additive result; not simply additive, but additive by co-organization of integrative kind. There, as Fernel insisted, the harmony of the whole is not merely built out of its parts but is impressed on the parts by the whole. An individuality whose whole, as luminously said by Coleridge, is presupposed by all its parts. A conception which has been revived notably by General Smuts as holism; German so-called 'figurism' has recently dilated on it.

I imagine the nearest to a differential characteristic of the 'living' energy-system is that the living energy-system, in commerce with its surround, tends to increase itself. It is like a train of fire which finds fuel for itself. If we think of it as an eddy in the stream of energy it is an eddy which tends to grow; as part of this growth we have to reckon with its starting, as we said, other individual eddies from its own resembling its own. This propensity it is which furnishes opportunity under the factors of evolution for a continual production of modified patterns of eddy. These patterns evolve some of

them an increasing complexity. It is as though they progressed toward something. But philosophy reflects that the motion for the eddy is in all cases drawn from the stream, and the stream is destined, so the second law of thermodynamics says, irrevocably to cease. The head driving it will, in accordance with an ascertained law of dynamics, run down. A state of static equilibrium will then replace the stream. The eddies in it which we call living must then cease. And yet they will have been evolved. Their purpose then was temporary? It would seem so.

The ' motion ' of an energy-system is its ' behaviour.' Various types of organization of system produce on that basis various types of behaviour. A grey rock, said Ruskin, is a good sitter. That is one type of behaviour. A darting dragon-fly is another type of organization and another type of behaviour. We call the one alive, the other not. But both are fundamentally balances of give and take of motion with their surround. To make ' life ' a distinction between them is at root to treat them both artificially. Fernel invoked the sun; the solar energy is a circumstance belonging to the energy-surround for both. We may consider the dragon-fly the more delicately balanced system with the more intensive give and take. Directly and indirectly through the collateral system of the green plant, it has the more acute commerce with the energy-system of the sun. We may judge it a more organized and integrated system than the rock, and it is certainly the more fleeting one. But these are details when we view energy-systems generally. Then, as pure energy-systems, rock and dragon-fly come together within one category.

But if there be no essential difference between ' life ' and all the rest, what becomes of the difference between mind and no-mind? There is that to be answered. To answer we may follow this hierarchy of systems and things downward and see at what point mind quits it.

Unless we can do that who knows that mind *has* left it? Of ourselves, yes, we know we have a mind. And the dragon-fly? Yes, it may have a mind. And, amoeba? It may have, but how are we to know? Then of the grey rock? Do we know? If the imagined boundary between life and no-life will not stand examination, may it not be that that between mind and no-mind will have to go?

For Fernel rock and dragon-fly were utterly and irreconcilably apart. They were kept apart because 'life,' an 'incorporeal' principle, was in one and not in the other. Traditional use of old habitual words tends to conceal their drift apart. Thought on this subject has moved far since Fernel. We see it when we reflect on its repercussions for the physician in the sick room. To-day the body's problems present themselves to him as chemistry and physics. Alas, for Fernel, by reason of his time, of physics he had little and of chemistry still less. But, even further from to-day than that, he studying his patient could not guess that in chemistry and physics lay the direction of his problem.

Life as an energy-system is so woven into the fabric of Earth's surface that to suppose a life isolated from the rest of that terrestrial world, even for the shortest space, gives an image too distorted to resemble life. All is dovetailed together. The very place of each concrete animate thing is its own place, and any other would misfit it. Here too we differ from Fernel and his century. He could in thought transfer the life, the subject of his study, from our earth's surface to the stars and back. He had fewer criteria than we. And he had in thought a substance, a principle, self-contained and free, indivisible, immortal, and otherwise undefined. We remember how vastly the almost inconceivably small and the almost inconceivably great have extended since then. Yet in doing so they have left no gap between their extremes. In the immense jig-saw puzzle there is but one place into which each several piece will fit. Of

translocation such as Fernel's pious fancy pictured little possibility is allowed.

Life, as we know it, is always specific—specific in time and place. Surely, it is of where and when it is, and of no other where or when. All of life as we know it could exist probably nowhere else than on this planet's surface, where it is. Even our near neighbour, the moon, offspring, as are we, of our own planet, would be too uncongenial, too cold and waterless and airless; life there would perish. Nor would it tolerate Earth's nearest sister, Venus. Nor could our good neighbour Mars in all neighbourliness give, virtually without oxygen as it is, hospitable asylum to any life vagrant from us. The types of system which here 'live' would not subsist or maintain themselves there. A life on Jupiter would be bathed in clouds of solid particles of methane and ammonia. Mars, however, is said to have a something of its own which exhibits seasonal growth and change.

A great American physiologist, Lawrence Henderson, has set forth * the particularity of the physical and chemical conditions whose concurrence on Earth's side render possible the existence of the systems we call 'living.' Certain anomalous properties of water, in conjunction with unusual powers and space-relations of the carbon-atom, along with exceptional conditions of radiation and temperature, are shown to form a sort of conspiracy of circumstance allowing life to be, and here and now. There was a stage 'in the dark backward and abysm of Time' when our planet's side was not as yet a place possible for the life now around us. A stage ensued, however, when things would by a bare margin just permit the type of energy-system we speak of as living. Slender though that chance, it was, so to say, seized. Life appeared. Perhaps in some warm runnel of tidal mud or frothy ooze. It would, we must think, be a tiny thing, perhaps clustered and numerous; to all outward appearance impossibly fraught with what it has

* *The Fitness of the Environment.*

become to-day! It was, we may think, perhaps numerous, but in microscopic specks. Yet its destiny was to invade the land and clothe continents with its growth. To venture ocean and in time to populate it. To populate it with countless millions of feeding mouths, and to feed them, while their fins oared them about, fins prophetic of the bird's wing, and of the human hand. Millions of feeding mouths voiceless but yet potential of birds' song and human speech. Mere mechanism and yet charged with germinating reason.

Here the Cleanthes of Hume's Dialogue might tell us that for this the preparation of Earth's surface was. That it was *for* the advent of life. That conspiracy of circumstances which has been pointed out as affording unique opportunity for life to be was itself, he might tell us, a preparation for the event in store. It was all in expectation and foreknowledge of the peculiar conditions attaching to life, without which life could not be. So the conspiracy went forward. So, he might tell us, with that extension of living forms, which has come to pass, each new form finds within the general structure of the Earth's side some niche ready for it. A benevolent place in the economy of Nature which permits it to thrive, a nest as it were, made ready for it to house and breed in and where its young may be reared.

To this, his antagonist of the Dialogue, a Philo of to-day if we may venture so far, might perhaps rejoin: "Cleanthes, are you not treating as one thing two which are not similar? You speak of the beginnings of life on the earth, and then of the extension of life's forms which has come about on the earth's surface since life's first advent here. We accept this latter as a fact because the factual study of the earth's history documents it to us. In the serial millions of years which have passed since life appeared new forms of life have arisen, all of them variants of its one broadly taken central pattern. But that diversity can possibly be taken as evidence of an adaptability on the part of this type of energy-system

which we call life, enabling it to adjust itself to different conditions within limits and still to persist as a moving equilibrium fulfilling the requirements of its own replenishment and repetition. An eddy in a stream can survive many changes in the form of the channel. That it does so does not presuppose that an alteration in the channel was made just such as may allow the eddy to persist. In regard to the appearance of new versions of the form of life it seems simpler to suppose that the proved adaptability of the living system allows it readjustments within limits to circumstances of its surrounding. That seems simpler than to predicate for the surround or for the total economy, life and surround together, a prescience of futurity, not to speak of a prescient activity which commands design."

May we suppose Cleanthes to accept such possibility, and Philo to continue, "But the initiation of living systems, that is a different problem. The living system as we see it and as its history, traced to the extent we can trace it, exhibits it to us, has the character of adaptation. That is an observed datum recognizable in its behaviour since it arose. But for the living system to come into existence we have to suppose that it arose from some other form or forms of energy-system. In other words from some system or systems which we should not call alive. How such a system or systems could change so as to behave as living systems behave is a problem less open for us to judge because we do not observe it in process. The existing facts of to-day give little help. A metamorphosis of non-living matter into living is going on to-day. But it is not going on in the meaning we had in mind.

"The turning of non-living energy-systems into living ones does go on to-day, and wholesale. Lifeless energy-systems, from the air and soil and the sun's radiation, the plant builds up into the living energy-systems of itself. You remember what old Lucretius very prettily said—though I know you do not agree with him in some ways.

Praeterea cunctas itidem res vertere sese;
vertunt se fluvii frondes, & pabula laeta
in pecudes, vertunt pecudes in corpora nostra
naturam, & nostro de corpore saepe ferarum
augescunt vires, et corpora pennipotentum.*

" These transformations of lifeless into living offered no mystery to Lucretius. He trusted his enchanted 'atoms' and they did it. How they did it he leaves unsaid. So we must be content with that, and can follow him no further. Neither was this quickening of dead food into life a puzzle to our good Fernel. He had like Lucretius his fairy-like agents, only with him they were called 'faculties.' Fernel tells me † my breakfast once in my veins and hey-presto with a stroke of the wand—or more precisely with two strokes—life is conferred on it. The first stroke, given by *facultas procreatrix*, prepares the matter to receive 'form,' i.e. the principle of life; the second by *facultas altrix* actually confers the 'life.' You may judge it a calling 'of spirits from the vasty deep.' But that is the sole difficulty; that granted the rest follows.

" Cleanthes, the difference between my rose bush and me—aesthetics apart, where I know it has the advantage—is a question largely of how we feed. I, or my friends for me, must quest about for the food I take; but my rose bush quietly feeds on the soil and air it is in. That makes it a restful neighbour, whereas I am a restless, even an aggressive, one. The herd in the meadow are peaceful compared with the fly-swarm which teases them, but the green elms are peacefuller still. These feed and grow statelily enough on the very soil and air with which they stand in contact. But I, more like the herd and fly-swarm, have to quest for, and run after, my food. The lifeless systems I can vivify I have to seek and ransack for. Unless I get them I lapse. At root that it is which gives me nerves and makes of me a restless, even aggressive, fellow. Yet after all there is—aesthetics apart—

* *De Rer. Nat.* ii, 874. † *Physiol.* v, 3, 99.

greater likeness than unlikeness between my rose bushes and me. Standing there side by side taking the same soil and air one as another, yet this one stays 'Maréchal Niel' and that one 'Gloire de Dijon.' So too, you and I, Cleanthes, may share the same slice of breakfast toast and butter, and your piece will become Cleanthes and my piece Philo, and one is destined to think in terms of beneficent Design, the other in terms of materialist Determinism. Physiology says every item of our body is renewed within a certain space of weeks or months or years. We are no longer in that age, when the comment of the learned on Roger Bacon's famous woman of Norwich who fasted for 20 years, was that to fast is no more marvellous than to need to eat.* We have to be renewed, and our renewal is from energy-systems not in ordinary parlance alive. An instance of the scale of this creating, so to call it, of living matter from non-living, is what happens with the living speck of the egg-cell. In the course of 9 months this speck grows to a living bulk 15,000 million times greater than it was at outset. This increment of living energy-system has been created from non-living energy-systems under the starting influence of a tiny speck which is alive. As that initial speck was specific so is the whole train of increment. Even more it is personal, John Brown or Mary Smith, with a personality, inalienably patterned on that of the initial speck.

"Now such a transition from lifeless to living is thinkable if it be at root an affair of chemical rearrangement. But as transition from one fundamental category of things to another fundamentally different one it is unthinkable. The living and the lifeless studied as energy present no difference that rearrangement of their parts will not account for. The transition between them will be reversible, lifeless-living, living-lifeless, as in fact we know it is.

* N. Oresme, *Quodlibeta*, 1370. See L. Thorndike, *Hist. of Mag.* iii, 456.

"We must not, however, think it quite the gross affair our physiologists of last century seemed to leave it at. It is not just a question of a quantity of energy supplied in standard patterns, carbohydrate, fat and protein, together with a little mineral salts. A diet cannot be valued simply by calories as a town gas-supply by therms. A diet with sufficiency of calorie-value and correct quantities of the standard chemical patterns may yet be inadequate, though it become adequate on adding a very little raw milk. Observing this, the idea opened before Hopkins that there was a question of food-factors hitherto unrecognized though indispensable for a fully nutritive diet. It was shown that a whole menu of the classical chemical entities might yet not sustain animal growth until a little of an undiagnosed specific food-factor was added (Osborne and Mendel). To those who made such experiments it became clear that a healthy diet asked for certain substances not yet identified by the chemist, but needful for health, although in minute quantity. Instances multiplied. The unidentified indispensables became called 'vitamins.' Some quarters, in continental Europe, were slow to follow the lead. They did not admit the existence of such bodies. They were thought 'ill-defined hypothesis.' Time has answered by demonstrating six pure chemical substances, isolated and of ascertained chemical constitution; three of them already actually synthesized in the laboratory.

"The vitamins are now some dozen in number. They prove to be no homogeneous chemical group. If you ask me, Cleanthes, for a definition of a vitamin, all that I, who am no chemist or physiologist, can offer is that it is a something of the class the chemist calls 'organic,' which, although in minute quantity, our life wants over and above the mass-fuel of carbohydrates, fats and protein, and wants presumably for particular and specific pieces of its chemistry. Unversed as I am, the position reminds me of an old popular view once voiced by the shibboleth 'phosphorus for the brain.' I fancy there

the brute fact was that our brain contains phosphorus compounds, and we can add a phosphorus compound to our breakfast food; and that there the argument stopped. With a vitamin, however, an ascertained bodily faculty—to use Jean Fernel's word—is found to need it and to fail when the food does not contain it, or enough of it, and to recover when the food does supply it.

" There is that child, your neighbour's child, Cleanthes, whom it is pleasant to see with its grace of bearing and the dainty teeth it speaks across. Its parents' care and good circumstances have provided it, Lady Mellanby might tell us, with a fairy god-mother called vitamin D. A good fairy presiding over the bone-forming salts and the formation and arrangement of the teeth, and keeping away dental caries. It is a charm against rickets. And now well enough known and recognized to be prepared in purity on a practical scale; and to be assayed in international units at the National Institute for Medical Research, where under Dale its purification was first accomplished. It had no established place in the idea of diet a generation ago. And there is vitamin A, a good angel for growth and against bacterial infection. It occurs more liberally in ordinary foods, in butter and eggs and greenfood. But it depends on sunlight, and on rays in sunlight which our ordinary window-glass does not transmit. It requires the sun and is best from May to September. There is therefore a seasonal variation of it in the dairy-produce our diet draws on. It, too, is obtainable pure and is assayed in international units. These are but samples. There are vitamin B, vitamin C, vitamin E, and B is a whole group in itself, B1, running to B6, a ' full-sized swarm.' Each of them all contributes its something toward health. Thus, lack of one brings scurvy, lack of another rickets, of another polyneuritis, of another a form of sterility. You are smiling at the unfairy-like names of these good fairies. Their names were non-committal in order that scientific ignor-

ance should not be cloaked. Under fuller knowledge they are already being rechristened properly and chemically. Vitamin C is ascorbic acid (Szent-Györgyi), and is generally so spoken of. Vitamin A is β-carotene.

"All this has been a fine step in human knowledge, Cleanthes. Man is a disturber of the ways of life on his planet and not least a disturber of his own ways and old habits. Not so long since, we were content with flour from the near wind or watermill and we got milk from a near farm. Now we insist on flour more white and refined, and our milk is conveniently canned and condensed for distribution and storage. But these do not as did those protect any longer from ill-nutrition and scurvy and bacterial infection. Time's compensation is that we have now fresh fruit and green-stuff accessible and available by modern transport and cold-storage from distances and in seasons undreamed of in those former times. Our own wishfulness tied us up in difficulty which our own hands are now untying. If I dare speak for our race, Cleanthes, that has happened before: 'à longue échéance,' our detecting the vitamins is a further step towards our exploiting the planet, and to do that we must do as none of our sub-human predecessors ever had wit to do, we must take Claude Bernard's advice, and carry our own particular environment with us. To do that we must know adequately what that environment is, and now we know the vitamins belong to it.

"The knowledge has come opportunely, but it has had its difficulties. Their quantitative slenderness was one stumbling block in the path toward detecting the vitamins. A sufficiency of vitamin A for twelve dozen rats their life long is half a drop of its 5% solution. And not only is their amount escapably small but they are chemically fragile, and difficult therefore of chemical detection and isolation. We reckon the vitamins to food. But food such as sugars, fats, and we may add proteins, are of calorie-importance. The small amount in which a vitamin is effective is not understandable on its global

energy-value or calorie-value. We have to think their rôle rather as supply and renewal for some specific pattern or part-pattern in an organic molecule essential to certain cells. It may be that they are indispensable for certain catalyses. Vitamin B, which counteracts nerve-degeneration, is a so-called co-enzyme in oxidation (of pyruvic acid) in the brain (Peters).

"Many of us no doubt got on well enough before any study of the vitamins. The gourmet, Cleanthes, may not extol them even now. Nor presumably have they mattered much where, as with your neighbours and their child, the circumstances at their command supply a plenty and variety which, even unwittingly, embrace the whole quota of the vitamins. But the community at large has some of its children in sunless dwellings and some of their parents without the means of plenty. The study of the vitamins arms a community for instituting a nutrition sheet 'planned to safeguard the health of every citizen' * and his children. That also is a step toward our inheriting the planet we inhabit.

"It was a capital step of progress to find that our dieting was not so simple a matter as we had thought it. We had eaten and drunk somewhat as M. Jourdain had talked prose, without understanding the complexity of what we did. The replenishing of the living from the non-living is a more ticklish affair than we had light-heartedly supposed. Or perhaps we had left that mysterious transition from non-living to living as too akin to the miraculous to be understandable by us as process. That mysterious passage from 'lifeless' to 'living'—to 'life,' the indefinable, the inexplicable! Life, we know, can be fed with matter, but for us to comprehend that matter's becoming 'alive,' to trace it 'en passage' from one category of nature to another? Is it to be expected we should trace it? What question is there we can put to it about its change as it passes across the boundary from 'dead' to 'alive'? Yes; but suppose, Cleanthes, that

* L. Hogben, *Science for the Citizen*, p. 918, 1938.

boundary be a figment? The passage then too becomes imaginary. The difficulty becomes an imaginary one. Chemical partial repatterning might then be all, and quite intelligible to the chemist. The vitamins, too, drop then into their several places."

For Fernel, however, that the living body should be replenished and indeed formed wholesale from material which was non-living before incorporated, and then on incorporation became alive, would hardly need comment. It offered no difficulty where an immaterial life-principle tenanting the body vivified it all.

Recruitment of living from lifeless is going on in almost endless variety on land, in sea, and river, and unceasingly. But in all its instances its starting-point is already existent life. Every search for any other starting-point has failed. The individual as observed is always a bud from a previous one. This is an observational position relatively newly reached. Aristotle had no expectation of it. Nor had our physician-philosopher Fernel some eighteen centuries later. A century later yet and William Harvey had glimpsed it; "The living thing," he said, "is always from an egg, which again is always from a living thing." Later the problem assumed great practical importance from certain applications. It was seen that the essential fermentation-processes at root of many branches of industry (wine-production, farming, manufacture, and others), were due to microscopic lives springing up in the material used. If these arose not *de novo* but solely from specific seeds, then by controlling the access of wrong seeds, manufacture could be controlled and improved. Pasteur found that in no case did the germs arise *de novo*; that is, there was no 'spontaneous generation.'

It is impossible to prove a negative, but he challenged the world to show a positive contradicting his negative. The world has been trying to do so ever since on a colossal scale, for instance, through the fermented-liquor industries of the united world. But Pasteur's negative

stands unshaken. Again, Lister showed that the suppuration of wounds, erysipelas and septicaemia, and puerperal fever and so on, were similarly due to germs. Like Pasteur, he too never found the germs arise *de novo*. On the assumption that they never do, he devised measures for keeping their seeds out of the wounds. He banished suppuration and septicaemia from surgery. His negative statement that these myriadfold new individual germ-lives never arise except from pre-existing ones is being tested every minute over the civilized world—and no exception is found. If ever a negative came near proof, this may claim to do so. In so doing it rescues every year scores of thousands of human lives from suffering.

We may imagine this time Cleanthes turning to Philo. "Philo," he might say, "if matter, or as you prefer to call it 'energy,' did this thing—that is, produced life of itself—years ago, why should it not do so now? Perhaps, despite the evidence, you think it still is producing it?" Philo we can suppose to shake his head, and for reply remark "The conditions are not the same now as once." To which Cleanthes rejoins "They are favourable to life now, and that is what you say they were then." We can hear Philo mutter, "a matter of substrate and ferment." But to Cleanthes it had more in it than that.

Of behaviour observable in the cell, does any lie beyond the capabilities of matter according to to-day's conception of it? We are told to-day by some of those whose study it is, that practically the whole behaviour of matter is electrical. Cohesion, inertia, light, heat, chemical affinity, all are ultimately electrical. Matter almost resolves itself into the electrical. Electrical charges move from or toward one another, a behaviour which is transfigured into the metaphor, they 'attract' or 'repel'; they do so in regular ways, which is transfigured into the metaphor, 'they obey certain laws.' They group themselves into certain types of systems, groups called atoms,

because for a time thought indivisible like the speculative particles of the ancient 'atomists.' These groups can be broken up into their components and be reassembled. Again sets of groups are formed by the so-called atoms arranging themselves into further systems, molecules. They are electrical systems, as are the atoms gathered together in them. These groups make up aggregates whose behaviour presents itself in bulk as solidity, fluidity, colloidal state and the whole gamut of physical states. It is in accord with certain aspects of this behaviour that some mixtures of molecules arrange themselves as a complex of phases, the colloid state, with molecular aggregates often of molecules of great complexity. The colloidal state plays a great part in the living cell. As compared with some particles of the colloidal state, the smallest unit-lives themselves are but little larger. They are, however, all of them large enough to contain a number of molecules of the chemical classes, protein, fat and carbohydrate. These are commonly associated together in the organization of a complex which is said to live. Electrical charges grouped to atoms, atoms grouped to molecules, molecules grouped to aggregates of molecules, and, with this grouping reached, some of the smaller and more unstable of these aggregates balance their loss of energy for a time by taking fresh. Shall we suppose that anything has entered into this material to make it, unlike all the preceding organizations of matter, something over and above matter?

The cell feeds. The amoeba of the pond and the amoeboid cell of our blood, can be seen to take particles from the fluid around, and digest them. Is that to be accounted for by the properties of mere matter? These cells, seen by the microscope, are each a granular lump of jelly, continually changing shape. Changes in the surface-tension and the surface-charge at the interface between the cell and the watery fluid could account for this changing of shape, as it does for the meniscus of a

capillary electrometer. That changes in the surface-charge should occur is in agreement with the cell's chemistry. It is an extremely active chemical field. That the cell should make movements of its own is an outcome of such charges. With these movements the cell has a means of feeding itself. Subject it to steam-temperature for a minute; the movements cease, not to return. We may say the heat has 'killed' it. The movements were living movements. Chemistry, not knowing the word 'life,' says the proteins are irreversibly altered. The native protein-complex was a condition of those movements. The internal chemistry is altered. The cell feeds no more. Those movements were part of its feeding. Extrusions of the cell flowed toward the particle and round it. They engulfed the particle. Round the engulfed particle within the cell the fluid of the cell turns acid. The particle dissolves as it would within our own digesting stomach, likewise acid. There would seem in all this, remarkable as it is, nothing which the chemical system of the cell does not of itself carry through as chemistry. It can be conducted in absence of 'life' in a test-tube in the laboratory.

But the cell seems to *choose* some particles by preference. As a specialized chemical system the cell will react differently to particles chemically different. The cell's surface-tension alters in the neighbourhood of a sapid particle, as is understandable if the particle has any 'atmosphere' of solution round it. Even with simple acid and alkali the cells swarm to one or the other, obeying chemical principles entirely. It is the chemistry of a wound which directs our defensive cells thither. Mechanically injured cells extrude these substances which attract the amoeboid cells of the blood. That is verified by fact. The fluid moistening the abdomen does not attract them if the abdomen is healthy, but when the abdomen's lining membrane is irritated by the presence of foreign matter, or is inflamed, its fluid at once acquires the property of attracting the amoeboid

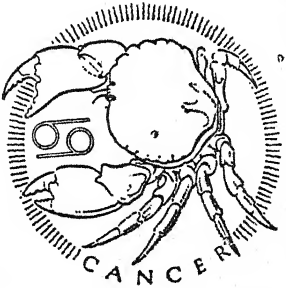
cells of the blood.* Again, injured muscle attracts the amoeboid cells, but uninjured does not. Their behaviour is not confined to indifference or attraction; it includes avoidance. Chicken cells are found actually to avoid healthy mouse cells. But injured cells, even if mouse cells, they run for. If we watch a pond amoeba we notice that some of the particles it eats are not food; but most are. With a chance collection of particles presented to it some of these particles modify the streaming of its cell substance, and these are eaten. A chemical atmosphere, so to say, surrounds a particle, different for different chemical kinds of particles. A chemical atmosphere seems to surround amoeba itself. Observers describe how the quick little *Colpidium* is captured by the slow amoeba. It swims as though attracted into the 'mouth' of amoeba. It is the chemical behaviour of the invading bacteria which brings our amoeboid cells thither to engulf and digest them. Our amoeboid cell as a physico-chemical system will treat the wound and the germs of disease as chemical factors and, doing so, do just what it does. And, so doing, defend the body. So obvious and significant is this last, that the surgeon watching and studying the behaviour of the cells, though knowing it chemical, calls it 'defensive,' as if it were inspired by purpose.

Does the cell, freely moving in the pond or in our body, *seek* its food? Is there some modicum of mind in it? That is a question natural to ask. It is not decisively answerable. It has seemed to some patient observers that the free single cell, for instance paramaecium, can be trained to some extent. That is, that it can learn. In short such behaviour is modifiable, and carries the inference that the modification is due to individual experience. If by experience here we mean mental experience, we may, I think, while not doubting the description of the observations, doubt this inference from them. Not

* C. G. Grand and Robert Chambers, *J. Cell. Comp.* 1936, ix, 172.

that there would seem any inherent unlikelihood in mind attaching in some degree to an individual consisting of one single cell. What was it Hobbes said? "I know there have been certain philosophers, and they learned men, who have held that all bodies are endowed with sense; nor do I see, if the nature of sense be set alongside reaction solely, how they can be refuted." * The improbability is, however, that mind of such degree should be recognizable by us as mind.

* *Element. phil.* iv, 25.



II

THE WISDOM OF THE BODY

Or a giggle at a Wonder. KEATS

Anatomize the eye: survey its structure and contrivance; and tell me, from your own feeling, if the idea of a contriver does not immediately flow in upon you with a force like that of a sensation.

HUME'S *Dialogues concerning Natural Religion*, Edit. KEMP SMITH, p. 191.

I remember well the time when the thought of the eye made me cold all over.

CHARLES DARWIN.

L'admiration est toujours une fatigue pour l'espèce humaine.

Le Bal de Sceaux.

II

We dismiss wonder commonly with childhood. Much later, when life's pace has slackened, wonder may return. The mind then may find so much inviting wonder the whole world becomes wonderful. Then one thing is scarcely more wonderful than is another. But, greatest wonder, our wonder soon lapses. A rainbow every morning who would pause to look at it? The wonderful which comes often or is plentifully about us is soon taken for granted. That is practical enough. It allows us to get on with life. But it may stultify if it cannot on occasion be thrown off. To recapture now and then childhood's wonder, is to secure a driving force for occasional grown-up thoughts. Among the workings of this planet, there is a *tour de force*, if such term befits the workings of a planet. Wonder is the mood in which I would ask to approach it for the moment.

The body, we said, is made up of cells, thousands of millions of them, in our own instance about 15 billions. It is a unity which has become multiplicity while keeping its unity (Carrel).* At its beginning it is just one cell, and the whole body is the progeny of that one. Hence the whole body is a million-membered family of cells whose ancestry converges back to that one ancestral cell, whose progeny it was. And that, in its turn, was from the ancestral cell of a next proceding organized family of cells. We are each and all of us instances of such families.

In each generation the impetus for the initial cell to produce its organized family is supplied by the coming together of it and another cell, outside its own family

* *Methods of Tissue Culture*, by R. C. Parker, foreward by Alexis Carrel, 1938.

stock, but not too far outside. In our own case and in the case of all our nearer kind, these two cells come from individuals of like species. The two individuals have to be complemental in sex. The fertilization-process which is preliminary to the train of growth of a new individual —what Fernel might have called its efficient cause— our description can dispense with, although it is highly interesting. The story of growth from a rounded microscopic speck to a shaped creature, is what we will glance at in outline. It is a story without parallel outside the world of life. Tracing it, even very briefly, we can then turn to judge of controversy about it. Before the coming of the microscope the earliest chapters of this life-story baffled the wisest. They were mere conjecture. When the microscope did come, it set itself to trace this Odyssey, this journey from a pin's-head egg to a grown man. Some saw as the starting-point of it an infinitesimal man. But that mistake was soon dispelled; the truth was stranger still. All there was to see was a speck of granular jelly, bearing no likeness to either parent or to man at all and no hint even of whether plant or animal, fish, fowl, or mammal.

Then at its outsetting that speck grew and, presently tearing its tiny self in two, made an adhering pair. Then they 4, 8, 16, 32, and so on; only to slow down after reaching millions upon millions. Not to stop altogether until by misadventure or, after years, by natural term, there falls on the whole assembly that subversive change called 'death.' So is made plain how it comes that the adult individual is nothing but assembled cells. Each of the cells from the beginning, besides shaping itself, takes up for itself a right station in the total assembly according to the stage which the assembly has by that time attained. Thus each cell helps to shape, and to construct as by design, the total assembly and the assembly's ordering of the moment. So it is that those early thirty-two cells dispose themselves as a little ball, hollow and filled with water. These thirty-two cells then

are a beginning stage of the individual to be, and the beginning whether beast or man.

Their visible arrangement taken at that stage gives practically no obvious hint of what the ultimate will be. Thence quickly, though gradually, change sweeps onward to later stage on stage. Darwin quoted the naturalist who wrote, "I have two little embryos in spirit, to which I have omitted to attach names. I am now quite unable to say to what class of animals they belong." Lizards or birds or mammals, they might be any of them. That kind of thing must have confronted Aristotle as a biologist; it may account for his habit of stressing a *final* cause. He insisted that to know a thing its final term must be known; in other words to know it we must know whither it is going. That was an injunction which Jean Fernel accepted from him and endorsed. In biology to jump at the final causes has many times led to mistakes. It did so notably with Galen. But it has also often solved problems. What it has achieved in biology does not permit us to despise it. It opened clues to Harvey. But in following it, Harvey never forgot that its following as a clue demands control by other evidence at every step.

The successive chapters of the story of the little ball of cells is like a serial transformation scene. The little ball can be likened, crudely enough, to a set of magic bricks. The one cell, the original fertilized cell, grows into two and those two each into two, and so forth. When that has gone on in the aggregate some 45 times there are 26 million million magic bricks instead of one. That is about the number in the human child at birth. They have arranged themselves into a complex, which is a human child. Each cell in all that more than million-fold population has taken up its right position. Each has assumed its required form and size in the right place. The whole is not merely specific but is a particular individual within the limits of the specific.

In that individual, that 'persona,' each cell has taken

on the shape which will suit its particular business in the cell-community of which it is a member, whether its skill is to lie in mechanical pulling, chemical manufacture, gas-transport, radiation-absorption, or what not. More still, it has done so as though it 'knew' minutely the local conditions of the particular spot in which its lot is cast. We remember it is blind; senses it has none. It knows not 'up' from 'down'; it works in the dark. Yet the nerve-cell, for instance, 'finds,' even to the finger-tips, the nerve-cell with which it should touch fingers. It is as if an immanent principle inspired each cell with knowledge for the carrying out of a design. And this picture which the microscope supplies to us, conveying this impression of prescience and intention, supplies us after all, because it is but a picture, with only the static form. That is but the outward and visible sign of a dynamic activity, which is a harmony in time as well as space. 'Never the time and the place and the "agent" all together.' Here all three and always, save for disease. The dominating forces are as diverse as powerful.

In its earliest stage the embryo's cells are not notably different from one another. Later a finished muscle-cell and a finished nerve-cell and a finished liver-cell are as far apart in visible structure as in what they do. They become so in spite of being by descent all members of one family. On the other hand, take of each similarly-functioning cells a pair, one from man and one from fish, and, though by descent worlds apart, the observer can read at a glance that members of a pair, alike in what they do, conform to the same pattern. The nerve-cell is as obviously a nerve-cell whether from man or fish. The dynamic stresses which so force apart and so draw together must be powerful indeed. In that way the cells of the various parts of the systematized assembly assume, as need is, special shapes, octagonal, stellate, threadlike, or what not. They, as the case may require, pour out cement which binds, or fluid in which they shall move free; or they hold hands for surer and more sensitive

contact. Some will have changed their stuff and become rigid bone or, harder still, the enamel of a tooth; some become fluid as water, so to flow along tubes too fine for the eye to see. Some become clear as glass, some opaque as stone, some colourless, some red, some black. Some become factories of a furious chemistry, some become inert as death. Some become engines of mechanical pull, some scaffoldings of static support. Some a system transmitting electrical signs. Each one of all the millions upon millions finally specializes into something helpful to the whole. It might serve as a text for democracy. It is as if the life of each one of all those millions has understood its special part. Thus arises the new integral individual to be..

To this there seems at first sight one exception. One cell-type which, out of all the myriads, alone remains its original self and does not specialize. It retains the old original nature of the ancestral cell. Its sisters and their progeny pass on through chains of metamorphoses to form a world of different shapes and activities. But this one persists still unmodified and true to its own primitive forebear. In a word it and its particular progeny remain germinal. It must be so, or there would be no future generation of the entire stock. To begin again there must be a return to the beginning. There is but this type to carry the whole family, as we termed it, on to a further generation. All its sisters with their flights into far-fetched specializations, including the brain with its mysteries of mind, are powerless to produce again a germ such as they sprang from. From no one of them all, let them be ever so human, can any fertilization produce their like again in the shape of man or human child. For that their sister cell, still generalized like the ancestral cell, is the sole means remaining. Hence from the old ancestral cell one narrow derivative line of descendants, nested in the rest of the immense specialized collateral progeny, retains its original germinal and general nature; and even this has to ripen. Significantly

enough it then sets itself free from all the others. And so from generation on to generation. This limited cell-stock, which can be called exceptional in that unlike its congeners, it does not specialize away from the parent germinal form, can be thought of as no exception after all. It is specialized for reproduction. It is clearly specialized in so far that only a special fertilizer can fertilize it. Its own specialization, as though by foreknowledge, anticipates among other anticipations what the nature of that special fertilizer will be. The whole astonishing process achieving the making of a new individual is thus an organized adventure in specialization on the part of countless co-operating units. It does more than complete the new individual; it provides for the future production of further individuals from that one.

More than half a million different species of pattern of life are, I believe, listed by the systematic naturalist as present current life. And each, as we say, 'breeds true.' This particular one we have followed is that to which the pair of cells, which made it, themselves belong, and they will make no other kind. But although of their species it is not quite like any other that ever was, and no other which ever will be shall be quite like it. It is not only man but it is the man John Brown, or the woman Mary Smith, whose exact like never was yet. This that pair of cells did as if they had been taught beforehand and many times rehearsed it. It was done likely enough without a hitch.

But the procession of change which for instance abuts in the human child has never come within the rôle of the actual ancestry of the fertilized cell which sets about it. All that has come within the experience of that ancestry has been the launching from generation to generation of that side-adventure which now terminates in fully completed man; the participation has gone no further than the launching. An explanation once offered for the evolutionary process traced it to 'memory' in the an-

cestral cell re-living its experiences. But such an explanation rests, even as analogy, on a misapprehension of the actual circumstances. It would be imagination rather than memory which we must assume for the ancestral cell; memory could not recall experience it never had. But the key of the problem is not psychical. Chemistry holds the key.

The few early units which formed the family when it was but a tiny ball take, so to say, into their counsel water. The ball they form is filled with it. The growing membrane, half-floating, can then fold. It shapes itself, it feeds, water is a generous solvent; and it admits electrical activities, chemical compounds separating with opposite charge. Water is the very menstruum and habitat of each and every cell. Water, within and without, allows the cell free scope for action. Water is a wonderful 'surround' and the germinal cell seems to appreciate that.

Water within and water without. The cell-surface becomes at once a boundary and a medium of exchange between two chemical worlds, one inside the cell, 'alive,' the other outside it, lifeless. The cells divide and divide and differentiate and differentiate. The total aggregate of the surface between alive and not alive becomes greater and greater, and endlessly qualitatively graded.

Step by step things shape. There appear, tiny at first, what to the eye of the expert are recognizable as rudiments of parts of the future creature. The brain is a set of three little hollow chambers, and, thrust from the hindmost, a short tube, the spinal cord. They were formed by the membrane folding over right and left, the side-flaps merging and so making a tube. Their membrane will come to be a patterned nest of branching cells all in touch directly or indirectly one with the other and, in man, approaching in number our planet's human population. The tubular chamber with its watery content persists, buried within the greatly populated membrane. It persists throughout life, a primitive vestige, a dumb witness

to far primeval times when not only man, but bird and mammal and even reptile had not yet come to be. That early step, in-folding to make a tube-like brain, belongs to the opening chapter of the story of the human embryo growing into a child, but it is a primordial step, which foreran by aeons the advent of the human form itself.

Yet this swift and sure drama at some detail in some scene occasionally fails of full enactment. Sometimes the child is born with its brain and cord not closed to a tube, but lying open as a furrow. Then the nerves, which from all over the body should grow in and make connection with the roof of the completed tube, may be found looking, as it were, for it; and they look for it in the right place. But they themselves are helpless. It is not there. Theirs would seem therefore a blind search. What kind of co-operation is this? Is the whole story just chemistry and physics? The outcome here is evidently that of a process which sometimes goes wrong. Such instances are not very uncommon. Fingers or toes may misgrow club-like together. One kidney may fail. The head may contain practically no brain. In the heart the window between lung-half and other half may not close at birth, so that the blood goes imperfectly aerated, and the child lives half blue with suffocation. What is the meaning of these failures in the issue of the plan? Where two calves of a birth are of opposite sex, the sex-organ of the female twin is found under-developed. Its development is checked by chemical substances which favour the male twin. In the cow the twins in the uterus have a circulation in common and the male hormones circulating through both inhibit the cow-calf. In the human case the circulation is not in common and this does not occur. The blood-supply of each twin is separate. Now, hormones are chemical substances. The instance makes clear that at least in this example chemistry controls the plan of the young creature.

Out of that little hollow ball of cells of the beginning, cells all looking much alike, differentiate and grow heart.

brain, gland, muscle, bone, skin, ear, eye; and, threading among them a network of tubelets, carrying the blood into reach of every cell in all the complex body. Also lines of nerves to take nervous messages from skin and ear and eye to spinal cord and brain, and other lines of nerves taking messages from spinal cord and brain out to the muscles. Can chemistry account for it all?

Even in relating this we drop into an old habit. We speak of nerves *for* doing this and that. This is the Galen in us. To do so comes naturally to the lips. And Galen in this was thinking as everyone thinks and was speaking for Mr Everyman, not merely of his own time but for practically ever since. Muscles seem made for what will be wanted of them. In the foetus a short channel joins the root of the lung-artery with that of the main artery of the body. Immediately following birth the lung enters activity, and this side-tracking of its blood-supply would be disadvantageous. A little before the foetus is actually born this channel is shut by a special small muscle. This muscle, "as far as is known never used in the foetus," "springs into action at birth" * and shuts the channel. "Having performed its function it degenerates" and disappears, the channel having in due course become obliterated under disuse. Sir Joseph Barcroft adds "it would seem very difficult to claim that the muscle which closes the ductus at birth has been differentiated as the result of any specific conditions to which it has been subjected—much less any specific use which it has subserved." †

Nerves seem *for* their purpose, constructed in view of what *will* be 'wanted' of them. Before ever they function they grow where they *will* be wanted, they make the 'right' connections, those they *should* make. We all drop into this mode of thought; we adopt it as we dissect. In the particular prodigy before us now, that of a microscopic cell becoming a man, we incline to read

* *The Brain and its Environment*, by Sir Joseph Barcroft, pp. 73–81. Yale University Press, 1938. † *Ibid.* p. 73.

the whole story in that way. We say 'it grows into' a child. Grows? Levers laid down in gristle, becoming bone when wanted for the heavier pull of muscles which *will* clothe them. Lungs, solid glands, yet arranged to hollow out at a few minutes' notice when the necessary air shall enter. Limb-buds, futile at their appearing and yet deliberately appearing, in order to become limbs in readiness for an existence where they *will* be all-important. A pseudo-aquatic parasite, voiceless as a fish, yet constructing within itself an instrument of voice against the time when it *will* talk. Organs of skin, ear, eye, nose, tongue, superfluous all of them in the watery dark where formed, yet each unhaltingly preparing to enter a daylit, airy, object-full manifold world which they *will* be wanted to report on. A great excrescence at one end of a nerve-tube, an outrageously outsized brain, of no avail at the moment but where the learning of a world *to be* experienced will go forward. All seems to argue prospective knowledge of needs of life which are not yet but are foreknown. All is provided; no detail is forgotten, even to the criss-cross hairs at entrance to a cat's ear which keep out water and flies (*Frontispiece*). Had antiquity or the middle ages been acquainted with the facts, they would have been set down to Natural Magic. Fernel's Preface (1542) wrote "as Aristotle says, to know the end of a thing is to know the why of it." And similarly to-day the biologist writes,* "we can only understand an organism if we regard it *as though* produced under the guidance of thought for an end."

Suppose tentatively, at pause before this riddle, we allow the premiss that in this developing embryo there resides some form of mind or psyche, and even in each of its constituent cells, and not inferior to what as human individual it has. Mind so present and intent on producing the child to be, would still be faced at every step with 'how.' It would be helpless. It has no

* R. C. Punnett, "Forty years of evolution theory," in Needham and Pagel, *Background to Modern Science*, p. 196. Cambridge, 1938.

experience or memory to have recourse to for the purpose. It is an aggregate of cells doing what they are doing for the first time and the only time they ever will. Yet every step they take seems fraught with purpose toward a particular end. The purpose clear, the 'how' of it obscure. Watching the limb-bud enlarge and shape without hitch to an arm, the surprise is not when all goes right but when sometimes something goes wrong. A finger fails. The process is fallible! Not the perfection but the freak receives our stare.

The microscope enables a more intimate glimpse. But the microscope merely resolves the mystery into some millions of separate microscopic growing points, each still a mystery. We ask what is the process going on at each of these? Again, how are they all co-ordinated to give a harmony of growth 'according to plan'?

Growth? The word in biology, employed I suppose since biology first was, took long in getting to grips with any intimate scientific 'how.' Its 'rapport' with chemistry and physics was not close. Its study consorted rather with that of gross visible shape, the shapes of life. Growth is of course a factor in their shaping. To record shape has been far easier than to understand it. The shaping of the embryo taken at its face-value is an amazing 'becoming' which carries 'purpose,' even as the wing of the insect or the stream-lining of the whale.

Because atoms combine on the basis of the arrangement of their sub-atomic parts we do not speak of those constituent parts as there *for* producing molecules. We do not speak of electrons as *for* producing atoms. Yet molecule-producing—and atom-producing—would seem as purposive as limb-producing. Our concept of an atom treats an atom as a deterministic necessity. To describe atomic behaviour science makes no appeal to purpose. In physics science would gain nothing by that appeal. Does it in biology?

In the study of biology the integral shape of the living thing has always held a prominent place. Such shape

is always specific and of decisive meaning to the life itself.* It was a study which as it became subtler and more conscious of its ultimate aim called itself morphology, so stressing better that it has for its object visible shape. Its technique, like that of anatomy from which it sprang, was, prior to the microscope, simple, requiring a few cutting tools and the naked eye. Hence it had been accessible to antiquity. Aristotle's genius ranging over the field of animal form, practically for the first time in science, discovered much and laid down philosophic foundations. He possessed, for his era, an encyclopaedic acquaintance with animal form, and he drew from it profound and far-reaching inferences regarding Nature. So too again, 2000 years later, it was comparative study of living shape which furnished Darwin with his main texts for his doctrine of the relatedness of living things by descent.

Aristotle in treating the nature of visible form used regarding it an *a priori* conception. Probably, all circumstances considered, that was well. We can think he got further by that means than he would by any other open to him and his time. Knowledge of material (matter) was too slender then, and for long after, to give him help in such a problem as the shape of living things. It was an age when, as to Nature, zeal for analysis commonly outran the means of factual knowledge. Aristotle argued that a concrete thing, a stone, a cloud, a tree, a man, comprises on the one hand its material and on the other, so to say clothing that material, its form, separable, not merely in thought, from its material. The material was perennial, the form transient, and so on. This, whether as synthesis or analysis, served well enough to be still satisfying in the sixteenth century of our era, as judged from our prototype of that time, Jean Fernel, and many others with him. Even two and a half centuries later it underlay the so-called Nature-philosophy which included,

* See Sir D'Arcy Thompson's *On Growth and Form* for a luminous exposition.

among its naturalists, Goethe. But it, and they in its respect, were then decadent. It had become part of a cult whose votaries out-aristotled Aristotle in regard to 'form.' . It stood with them for a creative élan which brooded in and over living nature. It created and, in creating, it aimed at an ideal. At an ideal leaf; or, in the creation of a vertebrate animal, at an ideal vertebra. It was allied to the 'ideas' of Plato, which Aristotle had discarded. Darwinism came later brushing it and them aside.

As the study of living 'form' became, by means of the microscope more minute and intimate, regions opened where the naked eye could no longer follow; 'form' was strikingly instanced by the microscopic cell. The study of cell-structure became part of the study of living form. The architecture of the animal was an architecture of its cells in the aggregate. It was the upshot of cell-structure. It was then more clear that gross animate form merely statically studied could not explain itself. Gross form had too long been accepted as static, and apart from all the rest of the concrete life, throbbing as that was with energy, and therefore motion. The pattern of the concrete life had been accepted too easily as an inactivity, as if it were no part of what the animal 'did.' It had been a study of space-relations in frozen Time. Hence it remained aloof from chemistry and physics. Whereas in fact even those portions of the concrete life which seem the more durable are only temporary equilibria, in an unhalting kinetic system. The "abstraction of structure and function is," happily remarks Professor A. D. Ritchie, "at bottom merely a question of what changes slower or faster." *

There is one aspect of life's shaping which has however always pointed plainly to a dynamics of living form. That is growth. An old commonplace of the text-books used to tell us that although growth is a term applied to crystals as well as to living things, crystal growth affords

* *The Natural History of Mind*, p. 183, 1936.

no clue to and no paradigm for living growth. That seems now too hard and fast a saying. New techniques have recently been enlisted for the examination of biological structure. One of them is that developed by the Braggs for their masterly X-ray analysis of crystal structure and growth. The cell not so long since was plausibly regarded as a colloidal droplet. A drop of amorphous colloidal suspensoid seems as remote as anything possibly can be from what we should call architecture. To appraise the living cell as such a droplet was to forget that the cell is always an organized integer. Its visible structure expressed that. If unified spatial plan is architecture the cell has architecture. As to the stones of its architecture, they are in one word 'proteins.' It is a protein fabric. The nucleus, centring it, is a nodal point for the cell's synthesis of proteins.

As for colloid, the proteins behave in several ways as do inorganic colloids. They are held back by membranes, they diffuse slowly, and so on. Protein particles were, not so long since, thought colloidal molecular aggregates, not single molecules. For one thing they seemed too large. The chemist for all his synthetic achievements cannot construct any molecule approaching in mass the protein particle. That particle when regarded as a cluster of lesser molecules, was therefore supposed indeterminate in size. But the protein particle is now at least in many instances known to be one giant molecule. It has the definite individuality which is the hall-mark of a molecule, where every constituent atom is indispensable for the completion of the structure. X-ray analysis yields a picture of the atomic architecture of the protein-molecule, an architecture found well worthy of the name. Likewise the ultracentrifuge in a different way gives data of the mass and figure of protein particles, and it too finds them to be giant molecules. Some are thread-like, others practically globular. Their potential variety of pattern runs to astronomical figures. The probability nevertheless holds

that one underlying style of architecture obtains throughout them. Their wealth of detailed pattern provides a practically inexhaustible * variety for life to build with.

Pure mechanical treatment affects these giant molecules to an extent not evident with smaller and simpler ones. They can be 'denatured,' that is warped in configuration, reversibly or irreversibly, by mechanical agitation or even by inclusion in the surface-layer at a boundary. The cell, and therefore the living body, are sponge-works of boundary layers. The protein coat of the fertilized egg-cell which restrains the daughter-cells from becoming spherical behaves as a sheet of elastic jelly. It can be cut by the 'microneedle' without loss of its rigidity. But mechanical agitation by moving the needle back and forth 'dissolves' it locally. The shape of these protein molecules is in certain cases traceably related to the mechanical properties of the animal structure. In wool-keratin the molecule has an extensible backbone which lengthwise pull unfolds to a more open zigzag. Hence the wool's reversible extensibility. Again, the immense significance of muscle to life rests on its property of changing length and lengthwise tension. This, it is claimed, is due to a protein-molecule of folding and unfolding type.

From the pattern of a molecule to the pattern of a machine seems at first a far cry. Yet if we take as our machine one of those fibres of which our muscles are built up a close connection between the machine and the pattern of its molecule becomes evident. The essential service of muscle to life is, quickly and reversibly, to shorten so as to pull. Its shortening is called 'contraction.' The importance of muscular contraction to us can be stated by saying that all a man can do is to move things, and his muscular contraction is his sole means thereto. Each muscle-fibre is a simplified miniature of muscle, in size just visible to the naked eye. A millimetre is $\frac{1}{25}$ inch; a large muscle-fibre may be 15 mm. long

* Prof. Leathes, Pres. Address, Physiol. Sect. B. Ass. 1926.

and 0.1 mm. across. A muscle is composed of bundles upon bundles of its fibres set lengthwise so as to pull on the muscle's tendon. Each fibre is seen by the microscope to consist of strands of lengthwise-running fibrils arranged in packets and bathed liberally in nutritive juice within the fibre. Beyond that, to further degrees of minute structure, the microscope can hardly carry. X-ray examination then continues the analysis. The unit of measurement is the millionth of a millimetre. The ultimate filament then resolves itself in countless lengthwise lines of giant molecules. Each molecule is about 60 $\mu\mu$ long by about 5 $\mu\mu$ thick. Such a molecule is, as molecules go, immensely large; it weighs about 500,000 times the hydrogen-gas molecule. It is a protein (myosinogen), and it is one of the folding molecules which by buckling back on itself becomes shorter. This seems to be the prime-mover of muscular contraction. Minute almost beyond our actual conceiving, its mechanical power is additively organized to a muscle-fibre in numbers which again are almost beyond our conceiving. A cross-section of our sample muscle-fibre would cut 150 million of them. It is as if for each mm.^{2} of a muscle's cross-section a set of pullers five times more numerous than earth's entire human population were aligned to pull co-ordinately in one and the same direction. And at the given command they are called into play co-ordinately in time. It is a command issued through the muscle's nerve. It may be a chemical message but it is transmitted electrically.

How it induces the molecules in their millions actually to buckle, we have still to wait to know. Suppose however, under electrolytic dissociation, some bends in the myosinogen molecule armed with NH_2 and COOH became alternately oppositely charged (attractive) they would draw together. The zigzag or spiral of the thread would tighten, to its greatest at the isoelectric point of the myosinogen. The mechanism of muscular contraction would then be electrolytic dissociation changing the shape

of the protein-molecule. This would agree with the modern rejection of the view of muscular contraction as an oxidation liberating energy for external work. It would make muscle essentially an electric motor, though quite unlike any man-contrived electric motor. Whatever the device, nature has contrived it on a number of independent occasions, for instance in the thread-stalk of little vorticella as well as in vertebrate muscle.

I have heard Professor Vivian Hill say that the design of a spade or the gearing of a pedal bicycle are found to have worked themselves out duly proportionately to the rates of performance of the human muscle-fibre. These latter were not scientifically known until Hill's own researches recently determined them. But traditional experience had here allied itself with technology and, although the scientific data were not known, had arrived at the pragmatic right. But when we turn to the muscle-fibre it has solved the incomparably more difficult problem of constructing a prime-mover fitting the biological situation, and it has had nothing mental to assist it, either in the way of tradition or design. That is a sample of the biological problem.

In the embryo, as it grows, gradients of mechanical pull and push as they arise and subside may affect and direct growth and shaping. Ross Harrison, a veteran observer, remarks that such mechanical influence is unmistakable. Chambers finds " Stretching a dividing Arbacia egg longitudinally does not impede its divisions, but stretching it transversely completely stops it." *

Such facts stress how central in the problem of animal growth we have to think protein-synthesis. Its mechanism is not well understood. There are however collateral facts which bear significantly upon it. One is that among proteins some are known which reproduce their kind. The instance comes from those submicroscopic agents

* *J. Cell. and Comp. Physiol.* 1938, xii, 2, p. 160.

of disease, called for that reason 'viruses.' Certain of these have been separated in crystalline state—a pledge of purity—and are then found to be proteins of giant molecular weight. These propagate; they reproduce themselves. The mechanism of this multiplication seems a ferment action, e.g. the virus-molecule acting as its own enzyme (ferment). In fine, this protein 'grows.' Again, as though to demonstrate that the self-fermenting protein gives a clue to biological growth, the 'gene,' that quintessence of growth, seems to be a self-fermenting protein. The gene is nowadays perhaps too familiar a term to need description here. It may, with some licence, be styled a quantum of heredity. But it has, with further licence, to be thought of as a seed which planted, though a quantum, grows. Each gene in the egg-cell embodies a unit 'character' in the make-up of the individual springing from the ovum. The gene is no creation of mere fancy. It is a concept which relates, on experimental evidence, a particular hereditary character in the developed individual to a particular visible point in the nucleus of the egg-cell. Each multiplication of the fertilized egg-cell carries with it a multiplication of the gene. The gene in the growth of the body may multiply to some billions of its original. It is situated in one of the nuclear threads. The nuclear threads are thought of as containing strings of genes. The estimated size of the gene makes it of the same order of size as a giant protein-molecule. A cell-nucleus is known to be a nest of ferments. The gene, thus conjectured to be a self-fermenting protein-molecule, is a master-builder both of plant and animal.

Experiment indicates that the abrupt change in transmitted 'characters' spoken of in genetics as 'mutation' can be brought about by 'radiation' applied to a gene. A modification of the gene-molecule induced by absorption of an energy-quantum would seem then to reproduce itself under the self-fermentation of the molecule. The mutation would be a 'quantal-step.' The rate of pro-

duction and reproduction of cell-substance under growth can be very high indeed, but in the hands of catalysts (enzymes) that is not surprising. In 10 seconds an organic catalyst will activate nearly 10,000 times its own weight of hydrogen peroxide. In a quarter of an hour the nucleus of an actively secreting cell will yield an amount of 'enzyme' nearly equal in volume to itself, in this case not for retention in the cell. Where synthesis, for instance protein-synthesis, is adding to the cell-system itself the cell *has* to multiply, for one thing because the necessary give and take between the cell and its surround sets an upper limit to the ratio cell volume/cell surface. This helps to illustrate how truly a cell is an integer in the living aggregate of the individual.

Its protein-synthesis is a determinant not merely of the living individual's brute bulk but of the individual's, so to say, vital shaping. A motion-picture photographed from cells in growth almost startles us by the intensity of the activity they show. Protein-synthesis is in flood —a riot of activity, but always an ordered riot. The specificity of enzymes is an element of mechanism which carries order far.

The mechanism of the shaping of the 'house of life' remained long refractory to enquiry. It remained plausibly a vitalistic mystery. It seems at last in process of yielding itself up to science. It becomes interpretable in terms of energy, along with other aspects of the body. For Aristotle 'form' stood at least for an activity in the life it shaped. To-day again it is seen as an activity; this time in the main a chemical response on the part of that energy-system which is the concrete life. The body of a worm and the face of a man alike have to be taken as chemical responses. The alchemists dreamed of old that it might be so. Their dream however supposed a magic chemistry. There they were wrong. The chemistry is plain everyday chemistry. But it is complex. Further, the chemical brew, in preparation for it, Time has been stirring unceasingly throughout some millions of

years. And in the preparation of it Time has rejected much. The brew is a selected brew.

Can then physics and chemistry out of themselves explain that a pin's-head ball of cells in the course of certain weeks becomes a child? They more than hint that they can. Bearing in mind their hints, let us turn to another sample. They claim to be the makers of the eye. A somewhat trite example, it has this difference from the more general problem. It samples, though in little, one aspect of that problem with especial clearness. A highly competent observer, after watching a motion-film photo-record taken by the microscope of a cell-mass in the process of making bone, writes his impression thus: "Team-work by the cell-masses. Chalky spicules of bone-in-the-making shot across the screen, as if labourers were raising scaffold-poles. The scene suggested purposive behaviour by individual cells, and still more by colonies of cells arranged as tissues and organs." * That impression of concerted endeavour comes it is no exaggeration to say with the force of a self-evident truth. The story of the making of the eye carries a like inference, perhaps even more vividly, the demand made on precision of construction being in the eye the greater.

The eye's parts are objects familiar even apart from technical knowledge and have evident fitness for their special purposes. The likeness to an optical camera is plain beyond seeking. If a craftsman sought to construct an optical camera, let us say for photography, he would turn for his materials to wood and metal and glass. He would not expect to have to provide the actual motor power adjusting the focal length or the size of the aperture admitting light. He would leave the motor power out. If told to relinquish wood and metal and glass and to use instead some albumen, salt and water, he certainly would not proceed even to begin. Yet this is what that little pin's-head bud of multiplying

* E. G. Dru Drury, "*Psche and the Physiologists*" *and other Essays on Sesation*, p. 4, London, 1938.

cells, the starting embryo, proceeds to do. And in a number of weeks it will have all ready. I call it a bud, but it is a system separate from that of its parent, although feeding itself on juices from its mother. And the eye it is going to make will be made out of those juices. Its whole self is at its setting out not one ten-thousandth part the size of the eye-ball it sets about to produce. Indeed it will make two eyeballs built and finished to one standard so that the mind can read their two pictures together as one. The magic in those juices goes by the chemical names, protein, sugar, fat, salts, water. Of them 80% is water.

Water is a great menstruum of 'life.' It makes life possible. It was part of the plot by which our planet engendered life. Every egg-cell is mostly water, and water is its first habitat. Water it turns to endless purposes; mechanical support and bed for its membranous sheets as they form and shape and fold. The early embryo is largely membranes. Here a particular piece grows fast because its cells do so. There it bulges or dips, to do this or that or simply to find room for itself. At some other centre of special activity the sheet will thicken. Again at some other place it will thin and form a hole. That is how the mouth, which at first leads nowhere, presently opens into the stomach. In the doing of all this, water is a main means.

The eye-ball is a little camera. Its smallness is part of its perfection. A spheroid camera. There are not many anatomical organs where exact shape counts for so much as with the eye. Light which will enter the eye will traverse a lens placed in the right position there. *Will* traverse; all this making of the eye which *will* see in the light is carried out in the dark. It is a preparing in darkness for use in light. The lens required is biconvex and to be shaped truly enough to focus its pencil of light at the particular distance of the sheet of photosensitive cells at the back, the retina. The biconvex lens is made of cells, like those of the skin, but modified to be glass-

clear. It is delicately slung with accurate centring across the path of the light which *will* in due time some months later enter the eye. In front of it a circular screen controls, like the iris-stop of a camera or microscope, the width of the beam and is adjustable, so that in a poor light more is taken for the image. In microscope, or photographic camera, this adjustment is made by the observer working the instrument. In the eye this adjustment is automatic, worked by the image itself!

The lens and screen cut the chamber of the eye into a front half and a back half, both filled with clear humour, practically water, kept under a certain pressure maintaining the eye-ball's right shape. The front chamber is completed by a layer of skin specialized to be glass-clear, and free from blood-vessels which if present would with their blood throw shadows within the eye. This living glass-clear sheet is covered with a layer of tear-water constantly renewed. This tear-water has the special chemical power of killing germs which might inflame the eye. This glass-clear bit of skin has only one of the four-fold set of the skin-senses; its touch is always 'pain,' for it should *not* be touched. The skin above and below this window grows into movable flaps, dry outside like ordinary skin, but moist inside so as to wipe the window clean every minute or so from any specks of dust, by painting over it fresh tear-water.

We must not dwell on points of detail; our time precludes them, remarkable though they are. The light-sensitive screen at back is the key-structure. It registers a continually changing picture. It receives, takes and records a moving picture life-long without change of 'plate,' through every waking day. It signals its shifting pictures to the brain.

This camera also focuses itself automatically, according to the distance of the picture interesting it. It makes its lens 'stronger' or 'weaker' as required. This camera also turns itself in the direction of the view required. It is moreover contrived as though with forethought of

self-preservation. Should danger threaten, in a moment its skin shutters close protecting its transparent window. And the whole structure, with its prescience and all its efficiency, is produced by and out of specks of granular slime arranging themselves as of their own accord in sheets and layers, and acting seemingly on an agreed plan. That done, and their organ complete, they abide by what they have accomplished. They lapse into relative quietude and change no more. It all sounds an unskilful overstated tale which challenges belief. But to faithful observation so it is. There is more yet.

The little hollow bladder of the embryo-brain, narrowing itself at two points so as to be triple, thrusts from its foremost chamber to either side a hollow bud. This bud pushes toward the overlying skin. That skin, as though it knew and sympathized, then dips down forming a cuplike hollow to meet the hollow brain-stalk growing outward. They meet. The round end of the hollow brain-bud dimples inward and becomes a cup. Concurrently, the ingrowth from the skin nips itself free from its original skin. It rounds itself into a hollow ball, lying in the mouth of the brain-cup. Of this stalked cup, the optic cup, the stalk becomes in a few weeks a cable of a million nerve-fibres connecting the nerve-cells in the eye-ball with the distant brain. The optic cup, at first just a double layer of somewhat simple-looking cells, multiplies its layers at the bottom of the cup where, when light enters the eye—which will not be for some weeks yet—the photo-image will in due course lie. There the layer becomes fourfold and of great complexity. It is strictly speaking a piece of the brain lying within the eye-ball. Indeed the whole brain itself, traced back to its embryonic beginning, is found to be all of a piece with the primordial skin—a primordial gesture as if to inculcate Aristotle's maxim about sense and mind.

The deepest cells at the bottom of the cup become a photo-sensitive layer—the sensitive film of the camera. If light is to act on the retina—and it is from the retina

that light's visual effect is known to start—it must be absorbed there. In the retina a delicate purplish pigment absorbs incident light and is bleached by it, giving a light-picture. The photo-chemical effect generates nerve-currents running to the brain.

The nerve-lines connecting the photo-sensitive layer with the brain are not simple. They are in series of relays. It is the primitive cells of the optic cup, they and their progeny, which become in a few weeks these relays resembling a little brain, and each and all so shaped and connected as to transmit duly to the right points of the brain itself each light-picture momentarily formed and 'taken.' On the sense-cell layer the 'image' has, picture-like, two dimensions. These space-relations 'reappear' in the mind; hence we may think their data in the picture are in some way preserved in the electrical patterning of the resultant disturbance in the brain. But reminding us that the step from electrical disturbance in the brain to the mental experience is the mystery it is, the mind adds the third dimension when interpreting the two-dimensional picture! Also it adds colour; in short it makes a three-dimensional visual scene out of an electrical disturbance.

All this the cells lining the primitive optic cup have, so to say, to bear in mind, when laying these lines down. They lay them down by becoming them themselves.

Cajal, the gifted Spanish neurologist, gave special study to the retina and its nerve-lines to the brain. He turned to the insect-eye thinking the nerve-lines there 'in relative simplicity' might display schematically, and therefore more readably, some general plan which Nature adopts when furnishing animal kind with sight. After studying it for two years this is what he wrote: "The complexity of the nerve-structures for vision is even in the insect something incredibly stupendous. From the insect's faceted eye proceeds an inextricable criss-cross of excessively slender nerve-fibres. These then plunge into a cell-labyrinth which doubtless serves

to integrate what comes from the retinal layers. Next follow a countless host of amacrine cells and with them again numberless centripetal fibres. All these elements are moreover so small the highest powers of the modern microscope hardly avail for following them. The intricacy of the connexions defies description. Before it the mind halts, abased. *In tenuis labor*. Peering through the microscope into this Lilliputian life one wonders whether what we disdainfully term 'instinct' (Bergson's 'intuition') is not, as Jules Fabre claims, life's crowning mental gift. Mind with instant and decisive action, the mind which in these tiny and ancient beings reached its blossom ages ago and earliest of all."

The first and greatest problem vision faces us with is doubtless that attaching to it as part of the matter-mind relation. How is it that the visual picture proceeds—if that is the right word—from an electrical disturbance in the brain? But as a sub-problem of high importance concerning vision comes that of pattern-vision. The study of vision, pursued comparatively in different animal forms, indicates that the primitive vision widely prevalent in simpler forms of life attains merely to the distinguishing of 'light' from 'no light.' It usually reaches the refinement of distinguishing grades of intensity of light. This primitive vision however does not attain to distinguishing shape or figure. It does not arrive at what is called 'pattern-vision.' Our own seeing makes so rich a contribution to the shapes of our world that it is a little puzzling for us to think of unpatterned seeing. To think of colourless seeing is likewise a little difficult; in many creatures, however, sight is colourless.

Over a great diversity of more highly developed vision, the eye supplies a definite image of what it looks at. There we must suppose 'pattern-vision'; without it the optical apparatus would seem wasted. In many cases the eye has means of focussing its image. That gives further development of the well-known relation between nerve and mind, namely that the '*place*' of a stimulated

sensual point acts on the mind; whence 'sensual space' with 'local sign.' It holds certainly not least in visual sense. If the sensitive sheet receiving the light-image be arranged as a mosaic of sub-areas corresponding severally with quasi-independent nerve-elements each with its access to 'sense,' then any light-image affecting two or more such sub-areas simultaneously begins to have 'shape,' or when affecting them successively begins to 'move.' The *spatial* pattern of the image thus acts on the mind. Different patterns acting differently enable mental distinction between them. For instance a moving object tends to 'catch' vision.

We know enough of pattern-vision in ourselves to recognize that it is the foundation of a perceptual analysis of our visible world which is of supreme service to us. We know enough of our animal kith and kin to judge that in their case it serves not greatly otherwise for them. We must think that in each instance a great nervous rallying-place for confluent nerve-impulses from the quasi-independent elements of the ocular-sheet and for reactions between them must be appended to the eye. And that is what is found. Serving the eye there are condensed masses of nerve-structure which examined by the microscope are thickets of seeming entanglement, doubtless replete with meaning could we read their scheme. These great nerve-ganglia of vision are familiar to the zoologist. He knows them in the ant, the bee, the squid, and most of all in our own stock, and especially in ourselves. Their complexity in the insect was what amazed even so veteran an anatomist as Cajal.

The human eye has about 137 million separate 'seeing' elements spread out in the sheet of the retina. The number of nerve-lines leading from them to the brain gradually condenses down to little over a million. Each of these has in the brain, we must think, to find its right nerve-exchanges. Those nerve-exchanges lie far apart, and are but stations on the way to further stations. The whole crust of the brain is one thick tangled jungle of

exchanges and of branching lines going thither and coming thence. As the eye's cup develops into the nervous retina, all this intricate orientation to locality is provided for by corresponding growth in the brain. To compass what is needed, adjacent cells, although sister and sister, have to shape themselves quite differently the one from the other. Most become patterned filaments, set lengthwise in the general direction of the current of travel. But some thrust out arms laterally as if to embrace together whole cables of the conducting system.

Nervous 'conduction' is transmission of nervous signals, in this case to the brain. There is also another nervous process, which physiology was slower to discover. Activity at this or that point in the conducting system, where relays are introduced, can be decreased even to suppression. This lessening is called inhibition; it occurs in the retina as elsewhere (Granit). All this is arranged for by the developing eye-cup when preparing and carrying out its million-fold connections with the brain for the working of a seeing eye. Obviously there are almost illimitable opportunities for a false step. Such a false step need not count at the time because all that we have been considering is done months or weeks before the eye can be used. Time after time so perfectly is all performed that the infant eye is a good and fitting eye, and the mind soon is instructing itself and gathering knowledge through it. And the child's eye is not only an eye true to the human type, but an eye with personal likeness to its individual parent's. The millions of cells which made it have executed correctly a multitudinous dance engaging millions of performers in hundreds of sequences of particular different steps, differing for each performer according to his part. To picture the complexity and the precision beggars any imagery I have. But it may help us to think further.

There is too that other layer of those embryonic cells at the back of the eye. They act as the dead black lining of the camera; they with their black pigment kill any

stray light which would blur the optical image. Further they shift their pigment. In full daylight they screen, and at night they unscreen, as wanted, the special seeing elements which serve for seeing in dim light. These are the cells which manufacture the purple pigment, 'visual' purple,' which sensitizes the eye for seeing in low light.

Then there is that little ball of cells which migrated from the skin and thrust itself into the mouth of the eye-stalk from the brain. It makes a lens there; it changes into glass-clear fibres, grouped with geometrical truth, locking together by toothed edges. To do the required pertains one would think to the optician's workshop rather than to a growing egg. The pencil of light let through must come to a point at the right distance for the length of the eye-ball which is to be. Not only must the lens be glass-clear but its shape must be optically right, and its substance must have the right optical refractive index. That index is higher than that of anything else which transmits light in the body. Well, it is attained. Its two curved surfaces back and front must be truly centred on one and the right axis, and each of the sub-spherical curvatures must be curved to the right degree, so that, the refractive index being right, light is brought to a focus on the retina and gives there a well-defined image. The optician obtains glass of the desired refractive index and skilfully grinds its curvatures in accordance with the mathematical formulae required. With the lens of the eye, a batch of granular skin-cells are told off to travel from the skin to which they strictly belong, to settle down in the mouth of the optic cup, to arrange themselves in a compact and geometrical ball, to turn into transparent fibres, to assume the right refractive index, and to make themselves into a subsphere with two correct curvatures truly centred on a certain axis. Thus it is they make a lens of the right size, set in the right place, that is, at the right distance behind the transparent window of the eye in front and the sensitive seeing

screen of the retina behind. Moreover they filter off the heat-rays which might do the retina harm. In short they behave as if fairily possessed.

I would not give a wrong impression. The optical apparatus of the eye is not all turned out with a precision equal to that of a first-rate optical workshop. It has defects which disarm the envy of the optician. It is rather as though the planet, producing all this as it does, worked under limitations. Regarded as a planet which 'would,' we yet find it no less a planet whose products lie open to criticism, in our case from themselves. Equally, on the other hand, in this very matter of the eye, the process of its construction seems to seize opportunities offered by the peculiarity, in some ways adverse, of the material it is condemned to use. It extracts from the untoward situation practical advantages for its instrument which human craftsmanship could never in that way provide. Thus the cells composing the core of this living lens are denser than those at the edge. This corrects a focusing defect inherent in ordinary glass-lenses. Again, the lens of the eye, compassing what no glass-lens can, changes its curvature to focus near objects as well as distant when wanted, for instance, when we read. An elastic capsule is spun over it and is arranged to be eased by a special muscle. Further, the pupil—the camera stop—is self-adjusting. All this without our having even to wish it; without even our knowing anything about it, beyond that we are seeing satisfactorily.

I must not weary you. As wonders, these things have grown stale through familiarity. The making of this eye out of self-actuated specks, which draw together and multiply and move as if obsessed with one desire, namely, to make the eye-ball. In a few weeks they have done so. Then, their madness over, they sit down and rest, satisfied to be life-long what they have made themselves, and, so to say, wait for death.

But the chief wonder of all we have not touched on

yet. Wonder of wonders, though familiar even to boredom. So much with us that we forget it all our time. The eye sends, as we saw, into the cell-and-fibre forest of the brain throughout the waking day continual rhythmic streams of tiny, individually evanescent, electrical potentials. This throbbing streaming crowd of electrified shifting points in the spongework of the brain bears no obvious semblance in space-pattern to the tiny two-dimensional upside-down picture of the outside world which the eye-ball paints on the beginnings of its nerve-fibres to the brain. But that little picture sets up an electrical storm. And that electrical storm so set up is one which affects a whole population of brain-cells. Electrical charges having in themselves not the faintest elements of the visual—having, for instance, nothing of 'distance,' 'right-side-upness,' nor 'vertical,' nor 'horizontal,' nor 'colour,' nor 'brightness,' nor 'shadow,' nor 'roundness,' nor 'squareness,' nor 'contour,' nor 'transparency,' nor 'opacity,' nor 'near,' nor 'far,' nor visual anything—yet conjure up all these. A shower of little electrical leaks conjures up for me, when I look, the landscape; the castle on the height, or, when I look at him approaching, my friend's face, and how distant he is from me they tell me. Taking their word for it, I go forward and my other senses confirm that he is there.

A wonder of wonders which is a commonplace we take for granted. It is a case of 'the world is too much with us'; too banal to wonder at. Those other things we paused over, the building and shaping of the eye-ball, and the establishing of its nerve connections with the right points of the brain, all those other things and the rest pertaining to them we called in chemistry and physics to explain to us. And they did so, with promise of more help to come.

But this last, not the eye, but the 'seeing' by the brain behind the eye? Physics and chemistry there are silent to our every question. All they say to us is that the brain is theirs, that without the brain which is theirs the

seeing is not. But as to how? They vouchsafe us not a word. Their negation goes further—they assure us it is no concern of theirs at all. "That the eye is necessary to sight seems to me the notion of one immersed in matter." Such was this disparation to J. S. Mill.

But to return to the making of the eye. It seems clear that here is a subject which might well test the point of view say of Lucretius on the one hand, and our sixteenth-century physician, Fernel, on the other. Knowledge of much of its detail is, of course, new since either of them. The marvel of it has not grown less for that. The impression of perfection and endless resource which it leaves as a creative exploit, is occasionally broken by disconcerting incidents; something goes wrong. Fernel would not ask, but Omar Khayyám we remember asked, "And did the hand then of the Potter shake?" Thus, in the matter of the optic cup. Just within the lip of it, which holds the lens, the rim of the cup thins and becomes the circular iris which gives the eye what we call its colour, hazel, brown, grey, blue as the case may be. The circle of it is not at first complete because the cup is fissured at one place so that in its circular rim there is a gap. Later the groove closes and the iris becomes a perfect ring. But in some instances it does not so close; there is a gap in the iris extending from the pupil as a notch. The defect does not occur at random. It runs in families. In that great multitudinous creative dance which we traced, if things are to go right for the finale, the evolutions of the part-figures must keep step, or certain partners may arrive late at certain places for partners who will then already have moved on. A point we have to note is that in this great dance once a mistake made there is no subsequent recovery. Moreover, the individual dancers seem blind themselves to any mistake which may have happened. Again, in the building of the nervous system where certain nerve-fibres have to grow far to join particular others also converging to a certain spot, their punctuality in keeping appointments counts for much.

The time-keeping in fact is not exact; in consequence no two individuals of us have a make-up of spinal nerve-roots quite alike. This gives the surgeon trouble if he has to operate on us. That misfits of this kind happen seems to suggest a fallible mechanism at work rather than a supreme ideal in process of heavenly accomplishment.

The successful making of the infant creature is judged far more subtly by the truth of the working of the resultant life than by any test which inspection by the eye or microscope imposes. For instance there is its endowment with colour-sense. That is, we know, sometimes defective. There are born those unable to distinguish as do most of us between red and green. The eye and retina, and everything is normal in them to the minutest microscopic examination; nor is any part of the brain, visual or other, recognizably defective. The defect haunts particular family stocks. It is related to sex; it goes with maleness. To the geneticist that is a clue. Sex is a feature, the development of which in the individual is traceable to a definite visible element in the egg. That element contains, along with potential sex, certain other 'characters' which are called 'sex-linked' because linked with the gene of sex. Each 'character' has its gene. Colour-vision is a 'character' related to a gene. Normality in this respect may be wanting in one parent. The defect lies in a gene which is of those linked with sex. In males a chromosome y, from the father, partnering chromosome x from the mother, is small. It lacks duplicates of some genes in x, and so may not cover defect in x. But in females a second x-chromosome, from the father, may cover such defect. The mystery which at first seemed to deepen with knowledge of the strange preference for one sex, on further knowledge tends to clear. It resolves itself into mechanism. Chemical mechanism, for the gene seems to be a catalyst of the chemical nature of a protein.

It is less than a generation since Edouard Gley, at the end of an address inaugurating the academic year in

Paris, remarked that 'Determinism' in the shape of Physics and Chemistry was, as a means of explanation, dominating Biology more and more. But, he added, one biological domain there is which it will never take over, the growth of the egg into a child. Time already belies his prediction.

One mechanistic factor seems to lie in an influence of one part of the growing embryo upon another part. We saw an instance in the eye-ball. A bud from the embryo-brain is the beginning of the eye. The skin over that bud dips down to meet it, and becomes the lens of the eye. Brain and skin, although separate, conspire and meet to build an eye. In the young tadpole the bud from the brain may be transplanted to a point distant from where the eye should be. At the new place the skin dips down to meet it there to form a lens for the eye which should not be there. At that new place the skin does just as would the skin of the right place. Again, if the skin from over the brain's eye-bud be replaced by skin from elsewhere, this latter skin, although not the right skin, dips down towards the eye-bud and forms a lens. Evidently an influence from the brain-bud extends to parts around. The biochemist tells us his next step will be to trace that influence to a particular chemical source. He speaks securely for he has done the like before.

Again, if a piece of that part of the embryo which is to be the main nerve-cord be removed, and its place given to other skin and taken from a region not destined to be nerve-cord at all, the new graft not originally destined to be nerve-cord becomes nerve-cord. The embryo at this stage seems pervaded by some general invisible plan which compels each of its localities, whatever the provenance of the material there, to become what is demanded there as part of that invisible but immanent plan. Later on, the trend in the local part to be what it set out to be becomes too strong to permit change. Then, the rudiment beginning to be a limb, will be a limb whatever happens, and wherever the experimenter puts it.

There is a time when a certain restricted bit of the embryo, in what will be the embryo's back, has a curious power, as so-called 'organizer.' If it be transplanted to some part of another embryo, it there sets going and seems to direct a wholesale scheme of development, almost tantamount to starting a new embryo. Something like this at times happens naturally. There are two kinds of twins. One kind is traceable to the fertilizing of two eggs. The twins then are not more like each other than are other children of the same parentage. In the other kind of twins both come from one and the same fertilized egg. What happens there is that the egg implanting itself as usual and drawing nutriment from the mother, its primordial cell mass, probably at first as usual just one embryonic rudiment, then proceeds to start a second embryo. These twins are always puzzlingly alike. The Canadian quintuplets are of this kind. In their case the same fertilized egg produced an accessory embryo not once but four times over. The 'organizer' explains how this might have happened. And the 'organizer' itself is receiving explanation as a chemical action, or rather as a set of chemical actions. A chemical extract has been obtained from it which shows organizing power. It is a substance of the nature of a sterol and has been isolated. Thus the organizing property of the 'organizer' is found to lie within the scope of chemistry.

This has collateral interest. The sterol is chemically akin to compounds now known to evoke cancerous growth. Its identification with this chemical group brings therefore the organization of the embryo into the same chemical picture as other growth, and that disease of growth, 'rickets.' Also with the chemical control of the menstrual cycle, and finally with the start and growth of cancer, misgrowth. There seems an underlying relation between them all, in nature chemical. As our sixteenth-century physician would say, that bids fair for medicine. A critic of Edouard Gley, of determinist pattern, would add, all looks like mechanism.

Our brief glimpse must not let us suppose that when the embryonic phase of life is over, this power of the parts of the body to 'become' reaches its goal and ceases. Suppose a wound sever a nerve of my arm. The fibres of the nerve die down for their whole length between the point of severance and the muscles or skin they go to. The skin there has lost sensation; in my muscles there I have lost my 'power.' But at once after the injury the nerve-fibres start to regrow from their cut points, even far up the arm. For three score years and more these, my nerve-fibres, have given no sign of growth. Yet after this wound each fibre, whether motor or sensory, would start again to grow, stretching out toward its old goal in muscle or skin. There would be difficulties in its way. A multitude of non-nervous cells busy on repair within the wound might spin scar-tissue across the path. Between these alien cells the regenerating nerve-fibre would thread a tortuous way, never uniting with any of them. This obstruction might take many days or weeks to traverse. Once through it, the young nerve-fibre would press on and reach a region where the sheath-cells of the old dead fibres would lie altered beyond recognition. But they and the new growing nerve-fibre would, as it were, recognize each other. Tunnelling along endless chains of them, it would arrive finally, after weeks or months, at the wasted muscle-fibres which were its goal. These too it would, as it were, recognize forthwith. With them it would unite at once. It would pierce their covering membranes. It would re-establish with them junctions of characteristic pattern resembling the original which had died weeks or months before. Nor would one nerve-fibre of all the thousands join a muscle-fibre which another nerve-fibre had already begun to repair. When all the repair was done the nerve's growth would cease. The wasted muscle would recover; in my skin which had become insensitive, sensation would return.

Nerve-regeneration seems a return to the original phase of growth. Pieces of adult tissue which have long

ceased growing, when removed from the body to artificial nutrient fluid, begin to grow. Epithelium, which in the body is not growing when thus removed, will then start growing. The cells then lose their adult specialization. In nerve-regeneration the sheath-cells and, to some extent, the muscle-cells which have lost their nerves lose likewise their specialized form. They regain it only when touch with the nerve-cell has been re-established. Mutual touch between cells decides much in their individual shaping and destiny. The severance of a nerve-fibre means loss of this touch. The severance, by rupturing that connection, removes something which restrains cell-growth and maintains cell-specialism.

There are further mysteries still. As we saw, a scrap of the heart of the embryo-chick put into a glass tube thirty years ago, protected from germs and fed, is growing still. Had it remained in its chick it would have died years since. In these instances of the behaviour of the body which we have been sampling—they are samples taken from thousands—two questions among many rise perhaps urgently for us here. Whence comes the means and whence the prevision? The eye prepared in darkness for seeing in the daylit world. The ear prepared in water for hearing in air. In the repair of the cut nerve, provision against a contingent accident possible enough which yet may never happen. Or, to take one sample more. The body practically never can suffer a wound without the tearing of some blood-vessels. That means loss of blood; and severe loss of blood can be fatal. The loss would always be severe and probably fatal if the bleeding did not stop. It would not stop, did not the blood solidify when and where and as it escapes. The blood clots and seals the point of escape. This solidifying is the work of an enzyme. The enzyme is ultimately traceable to a source in a particular gene. Some few of us are born deficient in this innate styptic. It is a defect which runs in families. It is sex-linked and that helps the geneticist to trace its gene to a par-

ticular element. Now, to do that is to trace it, and the normality it departs from, to chemistry.

Evidently the physics and chemistry of the cell can do much. Can they account for all that the cell does? That is, in short, can they account for life? Chemistry and physics account for so much which the cell does, and for so much to which years ago physical science could at that time offer no clue, that it is justifiable to suppose that the still unexplained residue of the cell's behaviour will prove resoluble by chemistry and physics.

Does the wonder then lapse of which we spoke at the outset? The cell's doings are affairs merely in routine conformity with ascertained ways of 'energy.' To apply the term *tour de force*, as at the opening I ventured to apply it, to any of these phenomena is out of place. Nor can we regard the 'human' as more wonderful than any of the rest. But a wonder is there still. True, we can understand Keats' sighing against science, "there was an awful rainbow once in heaven!" Yet he was "to find," as has been written of him, "material in the scientific view of the world for the highest achievements of poetry." Could we foretell the rose-bud from its chemistry, would that make its beauty less? Does such knowledge impair the beauty of the world? Surely the reverse, for we then know that such as the rose-bud are neither accident nor miracle. The wonder is there still. It rests on different ground. Nature is not made less wonderful because her rule of working begins to be intelligible. If it be a question of wonder, rather the more wonderful.

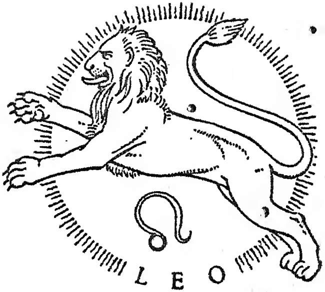
In this becoming of an individual as we have glanced at it, what of the old controversy about the essence of life? There is on the one hand our sixteenth-century physician-philosopher with his invocation of an immaterial principle to account for it, and on the other hand, not the ancient materialism of mere *a priori* speculation but the embryology of to-day. This last is a

body of systematized facts drawn from controlled observation and analysis, and on that basis marshalled and harmonized to a working conception. It is in short a likelihood grounded in fact and established by reason. Its methods are physics and chemistry. We would ask of it, does it find itself adequate to all the phenomena it meets in examining this development of the egg into the child? Is it adequate to describe this 'life'? Its answer is that it finds itself to be so. It says that it has no need, and therefore no room, for Fernel's 'essence' or 'principle' of life. Its answer does not mean that it is ready to account for every detail in the becoming of the child. Where there are millions of details there has not been time for that. But sampling key-instances and solving them it is left with the conviction that the problem before it, the problem of the how of this unfolding individual life, is one which it is solving and is competent to solve throughout. It repeats that its methods are 'chemistry and physics.' The concrete life in its maintenance was, we saw, a question of chemistry and physics, and the 'becoming' of its organism is so no less. Embryology to-day tells us that chemistry and physics are the solution of its problem.

Contrasted with this account furnished by scientific embryology, with its observations, and measurements, and facts, its agents and its technique, that furnished by our sixteenth-century Fernel presents a simplicity reminding us somewhat of a fairy-story. Yet in one respect it is a fuller account than is the other. "Our task," he says, "now that we have dealt with the excellent structure of the body, cannot stop there, because a man is a body and a mind together." * The message is in so far something like one of Professor Whitehead's to-day. Fernel's account of the becoming of the individual included the becoming of the finite mind. But, in the account rendered by our chemico-physical embryology of to-day, the latter's becoming might not be

* *Physiol.* v, I.

for any reference to it which is made. That is understandable as methodology; but it is usage to-day quite outside methodology. When we are told that the modern chemist and physicist cannot get on without the hypothesis that matter explains everything, a position is reached akin to that of initiation into a faith. A rigid attitude of mind is taken as an orientation necessary for progress in knowledge. Is there anything different between that and the efficacy of the spiritual exercises of St Ignatius as introductory to mystic convictions expected to follow? What either expedient may possibly gain in intensity of insight is surely at disproportionately greater cost to breadth of judgment.



III

EARTH'S RESHUFFLING

. . the course of nature . . . seems delighted with transmutations.

NEWTON, Query 30, *Opticks*.

The early lilies became part of this child,
And grass, and white and red morning-glories, and white and red clover, and the song of the phoebe-bird,
And the fish suspending themselves so curiously below there—and the beautiful curious liquid,
And the water plants with their graceful flat heads—all became part of him.

WALT WHITMAN, *Assimilation*.

I deem I was not made for heaven or hell
But simply for the Earth.

W. MORRIS, *Bellerophon at Argos*.

We are seamen of thy seas and we must sail.

E. N. DA C. ANDRADE, *Desire*.
[from Airs.]

III

There are words which some turn in the history of thought suddenly overwhelms with a large special meaning. Such a one is evolution. We might prefer to qualify it as 'biological evolution,' were it not that, scientifically speaking, the distinction between 'living' and 'lifeless' seems somewhat strained. The special connotation attaching to evolution implies that types of living things have, like human affairs, a history which can be traced, and that when traced their history bears witness to a progressive change whereby what they are is different from what they were. New types, the expression runs, have been 'evolved.' In the course of their history, in many cases more complex types have evolved from less complex. And that aspect of evolution is of particular interest to ourselves because we ourselves seem to be among its instances. We seem an outstanding example of it.

I would be clear as to what we may mean by 'new' evolving from 'old.' 'New' signifies here no more than a fresh arrangement, a reconstruction, a novel combination, of parts, the parts themselves not other than those existent before. New therefore in the sense in which we speak of new machinery which is but modified older. The new machinery is evolved from the old, in the sense that the old has been a starting point for the new, either in design in the hands of the designer or in material in the hands of the craftsman. This is not the same scope as M. Bergson gives his 'évolution créatrice.' There, as is usual where 'creation' is spoken of, he means that something new springs into being *de novo*.

Biotic evolution, to use that term, is constantly producing new combinations of old parts; the parts,

themselves being often very elementary ones—e.g. electrons, protons and their primary combinations, their atoms. From these certain new molecules have appeared.

When the reshuffling is so radical as that, its results can be far-reaching. Evolution does reshuffle as radically as that. Molecules make their appearance of kinds which were not before. We may suppose there has been no advent of a new type of living thing without the production of some chemical compound the exact like of which had not existed previously, at least so far as concerns Earth. The evolution of a series of types of life includes the invention, so to say, of many molecules of pattern fresh to our planet. Evolution has in its time produced a vast array of new forms of life and in virtue of that an even vaster array of chemical stuffs. They lay, so to say, latent as possibilities of the planet but actuality had never called them forth. They are an instance on a huge scale of a new 'becoming.' A becoming which held within it the secret of life, for the progressive evolution of successive living types was its accompaniment. A book, a great book, waits I think still to be written on the chemistry of evolution. The material for it already fills volumes. But I would feel that it still wants telling as one connected story. I am not competent to put it before you even in outline. Almost every one of the great classes of chemical entities which we, quoting Dr Needham, cited as together essential for the organized system of living substance was a something unknown to earth before life came. Evolution has called up a new chemistry. Yet, fundamental to remember is that it is still the old chemistry, still the same chemistry as was in essence before life came. It shows no *fundamental* departure, though it is a rich extension of endless variety within certain limits. The old principles comprise it, the old subatomic elements supply it, a certain set of the pre-existing atoms furnishes all the atoms it requires.

It is in fine after all a reshuffling. That may remove it from the utterly extraordinary. On a smaller scale man himself to-day does the same thing; wittingly and of set purpose and knowing how to set about it. Does it seem strange that an unreasoning planet, without set purpose and not knowing how to set about it has done this thing to an extent surpassingly more than man has? It is to be remembered that Earth's periods of time have been of a different order from man's, and her scale of operations of a different order, and that man's cunning in this respect dates but from yesterday. Yet, we agree, it does seem strange.

It is perhaps more surprising that it should have dawned upon the human mind only so latterly that his planet was a place of freshly arising shapes and powers of life. There was evidence of it in all directions round him but he had somehow failed to see it. It now gives him a new conception of his planet and of his place there. The constant intrusion of such novelty into this world had escaped the notice of his forebears of antiquity. It had not escaped them that the world shows changes. But its changes they had glimpsed rather as recurrent cycles of change. A progressive change which could be shown to have produced the novel and then scrapped it, and produced the more novel, and then scrapped that, and was still going on in like fashion generating and trying-out the novel cumulatively, without halting for a moment, millennium after millennium, must, he now begins to surmise, be doing something which 'leads somewhere.' That was a conception antiquity had not reached. Their factual knowledge was not adequate to it.

It is strange but true that one among the animals should have been led to fancy itself so different from the rest as actually to forget that it was an animal. Of new biological stand-points which last century gave us one most fruitful has been that of man as one of the animals. The thought is after all merely a return to the common-

sense of Aristotle. But last century documented it with fresh facts. It "has had an enormous effect in improving our understanding of the world." *

Thinking the thoughts that man now does, there occurs to him that at some not too distant future he, or some form of life which succeeds his, will compass chemical syntheses of substances which in ordinary parlance 'live.' He already constructs many of the substances which Earth has constructed as parts of concrete life. He does not however forget that his new knowledge which he calls chemistry, from the black art of Egypt, discounts his quest by saying it distinguishes no such thing as life. It is enough here that evolution by rearranging old parts is constructing new harmonies, chemical and biological. It is composing new melodies from some of the same old notes.

We are set wondering where evolution began, that is, how low down in the scale of things. Lives have evolved from other lives. Was life itself evolved? Is there a gap between animate and inanimate such that evolution could not and cannot bridge? Philo we heard † judge that there was not. With the more conviction could he so view the whole panoply of Earth's surface in its every item—rock, wave, cloud, herb, tree, insect, fish, bird, brute and man—from start to finish and without exception, as offspring of the planet's side. Some, for instance Helmholtz, Arrhenius and others, have thought life's beginning on this planet must have been a seed drifted across space hitherward from who knows where. But life seems too narrowly terrestrial in its simplest characters to derive from any other origin than Earth's self.

The animate and the inanimate as we have seen are in their ultimate parts alike, and fundamentally so in the principle of their construction. Is then transition by intermediate steps from the latter to the former unthinkable? Not unthinkable. When we systematize, the

* C. G. Darwin, Galton Lecture, *Eugenics Rev.* p. 17.
† *Vide supra*, ch. i.

animate falls unconstrainedly into series with the inanimate. The animate then becomes merely a special case within the more general. Analogously, the chemistry of the whole series of the carbon compounds taken within the chemical system is merely a special case within the more general. Is then the transition between the inanimate and the animate unthinkable? No: but not observed.

The history of the planet, we are told, says that only after a certain stage of its cooling could the chemistry of life obtain. It says that not so very long after that possibility arose, life did in fact appear. Put untechnically, times until then had been too violent for life's relatively unstable chemical systems to maintain themselves. Four of the very commonest of the atoms went mainly to the making of these new systems for which possibility had arisen. Dynamically balanced systems, with 'governor' systems locked into them to regulate them, and retrieve the balance when it leans dangerously far. Physics shows that where 'phases,' for instance, liquid and solid and gaseous meet, special opportunities for interaction occur. Our planet offers such a place. What we call its surface is a great interface where phases solid, liquid and gaseous meet. They meet as rock and tide and air. At this interface many new systems could be formed and must have been. There it was that the new systems we are thinking of will have arisen at that particular stage of earth's cooling. They were complex, delicate, and individually short-lived as against many of the old systems of the field around them. But we are tempted to look at these differences as differences of degree rather than of essence. These, inasmuch as they were 'living,' would come under to-day's rubric biology, those others under physics. If we follow Professor Whitehead the distinction between biology and physics is that biology studies the more complicated organisms, physics the less complicated. Mr Monsarrat tells us the same thing. Do not at some point these

merge with those? At some time was there not transition to the one from the other? May we not think that our planet's side, at that stage of its history which began our history, was a stage so set that physical organization merged into and passed over into, using the word in its current sense, biological? May we not think it a situation which allowed possibility of transition from inanimate to animate, and that the possible took place? The transition occurs to-day but only under contact with existing life, existing life which, acting like a ferment, catalyses dead systems into living. Apart from that particular case, this transition appears to-day to be irreversible. Easy enough from living systems to dead, but not the converse. Was it so always? Surely the very existence of life answers, no.

Once having started, the systems which live proceeded in numberless instances to become more complex. In that respect the difference between, in Whitehead's phrase, the physical organism and the biological organism, increased. This progressive complication was the work of evolution. Often the more complex evolved from the less complex. What does the progressive change to greater complexity, which often accompanies evolution, do for life? What does the complexity add? Does it bring anything wholly new?

It increases size. Life is taken out of the region of the microscopic. That is not unimportant. We are in a world of different sizes where size counts. Life enters a different region of the scale. The things it can and cannot do differ from those which it could and could not do when microscopic. But to enter a different scale is not of itself to be anything wholly new. The component units of the individual are more numerous. Each of those units being a tiny quasi-independent life, the multiplication of units allows higher specialization of different parts of a compound whole, though the whole still remains an integrated system, a unity. That is one aspect of the increasing complexity which evolution stands for. The

individual has greater range of doing. Mere increase of the number of the constituent units need not of itself however carry far. There are examples where large numbers of unit-lives cohere and compose masses but, as regards ability to do, gain thereby nothing or little, because organization of the aggregate mass in fresh directions does not accompany their coherence. There is no further integration, no further 'individuation.' Organization with differentiation of component units for this and for that, and at the same time co-operation between them one with another so as to serve the unified composite life; that is the kind of complexity which evolution shows to be the more significant. It is an ampler integration. Does such integrated complexity, as we might call it, bring into being anything absolutely new? Does it create anything? Does it, besides extending the range and powers of life, introduce anything which simpler life has not? Is there anything more in man than in amoeba or paramaecium beyond amplification of powers of the latter? Anything different in kind? A new mode or category of life? Is the more complex something more than increase of complexity of a type of system already existent? We should hardly expect so. Yet it does seem to be so. The complexity introduces recognizable mind. It does so gradually, and nurses it into flower.

In turning to the facts of evolution as far as we observe and know them, we should wish a detachment of view not always easy to ensure; nor indeed, for some purposes, wanted. When we study an adventure which is largely the adventure of our own kin and ourselves, we are apt to take sides. In scientific appraisement it is well to try to forget any particular predilection, even man's. Not that we can forget it. But we may at least try to avoid some of what might be called our besetting 'anthropisms.' That is to say, egoism which can distort the picture we would see as it is.

We are thinking of the individual life, and life is always and has always been individual. There is here no ques-

tion of a 'universal' because any attempt at definition of life must start out with the concept 'individual,' otherwise it would not be life. In the early phases of life's existence on the earth, the living thing was in all instances, we may think, microscopic. Then in course of time, in the forms which interest us especially, it became larger, multicellular and much larger than microscopic. It emerged from the microscopic. But to say that is to put forth a somewhat sophisticated version. It will do for a headline, but is only a partial truth. In a sense we are still one-celled and microscopic.

Evolution tells us that the plants and animals of to-day are the growing-points of a genealogical tree; perhaps one single tree. Each generation in its turn has been the set of growing-points of that tree. Some of these growing points have in course of time come to produce more highly organized life than do others. The growing points producing highly organized growth trace back however along their stem to simpler prototypes. Their lineage converges as they do so. The whole genealogical tree traces back to some few relatively simple prototypes; it may be to a single one. Whether to one or to several it would seem that the type or types finally led to by the backward trail were originally in each instance microscopic.

In those branches of the lineal tree which bear the more complexly organized types of life, such as those of our own stock, the actual growing-point has a cycle of growth. On its way to provide the next growing-point in succession to itself, it produces what is sometimes thought of as a vehicle to carry it, a nurse for the growing-point. This vehicle is a many-celled individual. "The hen is the egg's way of making another egg." The growing-point is microscopic, but the vehicle is not. The vehicle produced from the growing-point is a coherent family of cells, a multicellular unity, a corporate life. In our own case it is what we regard as the human individual. Figuratively, the genealogical tree entrusts its next suc-

cessive growing-point to this corporate individual which is formed as a by-product from the previous growing-point. The organization of this individual is various in various branches of the tree. In some of them it forms the most complexly organized individuals which nature offers. But however well organized, it is always a by-product in the meaning that, from the point of view of the growth of the tree it is just a vehicle for carrying and nursing the next successive growing-point of its particular twig. If we ask the purpose of the body and of all its organs, its heart, its lungs, its brain, it is for the purpose of housing there the sex-cell. Its organization into an integrated individual may make it so effective in doing various things, that other aims than that which, speaking for the tree, it was formed for, namely the continuance of the tree, may seem to itself the more important. It may be so with man who is one of these vehicles. But as a growing-point of the tree itself, he is still microscopic.

In the vast majority of instances, remaining microscopic throughout a relatively brief life, he or she dies never becoming any other than a single microscopic cell. The chance of fertilization has been denied him or her. For instance, as a futile spermatozoon he is one of the vast army which does not survive. Such sacrifice is the rule; fertilization is the exception. Fertilization is his sole means toward becoming a growing-point not merely potential but actual. When, as exceptionally, he becomes an actual growing-point he is still one single cell and for a brief time remains so. But in his next or somatic and multicellular phase some of his cells may live individually for even a 100 years or more; in the centenarian some nerve-cells are centenarian.

As potential growing-point and as initial growing-point he is for the time being a single cell. It is by that single-celled phase of his existence he is connected with the tree, and traces with his prehuman forebears back along it for, say, a 100 million years. All that time, with every generation, he cast off a vehicle. Quite recently that

vehicle has come to take the form of man, or better said, since our being is 'doing,' has come to do as an individual what it is human to do. Among other doings it has come to think, as we say, using 'reason.' The time may come when, observing itself to be essentially only a vehicle for the next successive growing-point, this individual may reason that it is not worth while to be. On the other hand it may, considering what it represents in life, assess its rôle as a transcendent privilege, which the cumulative vicissitudes of 100 million years have, somehow, crowned it with. It may glory in the acceptance and fulfilment of a rôle fraught with capacity for progress.

In man therefore, as in many other of the lives which under evolution have come to be, the complete individual-life presents two phases, one unicellular and microscopic, the other the multicellular man. The one phase succeeds the other, it matters not in which sequence we take them. The phases alternate. They are links in a chain. The microscopic phase is shorter-lived. A growing-point, but at first only a potential one. A potential bud with which, that it may bud actually, another potential bud must conjoin. And these two, we are thinking of man and his kind, must come from two individuals, sexually different but of the same species.

We can understand a little from this how the tree while it grew kept each branch true in general pattern to that branch and yet not exactly mere repetition. Each particular life starts, so to say, doubly anchored in species, but with swinging-room between two individuals. The two potential growing-points represent the same specific type but two individual versions of it. The hereditary disposition to produce like kind is strengthened as regards the species but as regards individual likeness must be a compromise between two different specimens. A certain degree of fresh departure is assured. The multicellular phase which follows on the unicellular phase thus presents an individual unique of its kind. Professor Whitehead inclines to embrace under

the term organism the atomic and molecular aggregate of physics as well as the organisms of biology. If we do that, the inference rises that there has come with life an enhanced individuality of organisms, and that that is increasingly so in the forms where life evolves complexity. Individuality would seem, so to say, to be through complexity an *aim of life*. Yet we must not forget that physics is less able to reach its individuals; it deals with swarms and populations rather than with an individual *per se*. Can it judge of its individual?

As to the power of certain cells to produce a coherent progeny which proceeds to organize as a collective unity, a multicellular individual, how that propensity arose is, I fancy, little known. We accept the fact. Nor do we know closely when first it came to be. It goes back very far in the geological record of life. Be that as it may and however it came about, it was an event of fateful trend. It put into the hand of evolution, we may think, the most promising material and conditions which evolution ever had. Evolution proceeded to make with it lives of plant-kind ranging from the saprophytic mould up to the forest tree, of animal-kind from the worm and less upwards away to man.

There is a certain stability in Nature—a 'toryism' if you will—which makes old ways die hard. Thus with the human egg. Eggs, speaking in general, are of two types, the small type and the large type. The former, the sea urchin's as instance, have scanty food-reserves (yolk) diffusely scattered and not stored in one lump. Such an egg in its growth segments right across, the whole of the egg taking part in the embryo. The large type of egg, the hen's for instance, is a million times larger. Its yolk is immense, and that part of the egg which makes the embryo is restricted to a tiny 'germinal disc' discrete from the yolk. Now the human egg is a very small one and its yolk is negligible, and like a yolk-free egg the whole egg segments up. Yet for all that it belongs ancestrally to the big-egg type; and it shows

very clearly that it does so. It segments right up but only a little part goes actually to making the embryo. The rest forms accessory structures such as a 'big' egg does, as if for the embryo to draw on a great yolk-store. The key to this behaviour is ancestry. The mammals—ourselves for instance—belong by ancestry to the big-egg type. We derive from the reptiles. The reptiles laid 'big' eggs and their doing so was a key-feature in their history. The big reptilian egg provided its embryo with a bath which, immersing it, did interim duty for the sea. It was one of the devices which emancipated the reptile from life's universal bondage by the sea. The reptile evaded the sea and took to land. Its migration proved an enormous success. The reptiles peopled the land. Exploiting the land they became in their time the living masters of our planet's side. They swam, they flew, and they walked the earth. Some of their kind attained gigantic size; the ooze quaked with their tread. They had their era and then, unaccountably, declined. But some of their smaller fry had been providing themselves against vicissitudes, not with armoured hides and immense thews but with a furry skin and milk-giving glands and an embryo which for its early period was parasitic on its mother. These aberrant reptiles avoided the perilous winter-sleep by intrinsically managing the body as a furnace. They seemed to know what Lavoisier was to discover, that 'to breathe is to burn.' These early mammals like their reptile ancestry had 'big' eggs and laid them, as primitive Australian Echidna documents to us to-day. But in the mammals as they evolved the large egg dwindled, the yolk becoming less and less. The embryo drew more and more its direct nutriment from its mother. The egg nevertheless still retained its old ways of the luxurious big-egg type as if it had huge reserves of food-yolk to draw upon—only the reserve of nutriment it now turned to was the blood circulation of its mother. It now sucked in the approved big-egg fashion not yolk, but its mother's juices through a

placenta. The old habit of life was not departed from, not scrapped; it persisted, turned to account in a new way. It was like Pareto's description of traditional ceremonial in England, the old bottle but a new vintage.

Just as structure once established is slow to disappear so too is 'process'—the distinction between them is but artificial. On the Antarctic ice the penguin, since first it was a penguin, can never have seen a tree. It cannot fly. The wing is dwarfed to a little paddle. Under it the head cannot possibly be tucked away, the wing is far too small. Yet faithful to the habit of forebears thousands of years before, the penguin when it composes itself to sleep turns its head and puts the tip of the beak, it can no more, under its midget wing. The buttons on our coat-tails once attached a sword; but such retention of habit is as nothing to the penguin's. Yet Nature, often as she hugs the old, seems seldom or never to revert to a past once abandoned. The ocean whale might dream of bygone land-pastures sooner than would its limb-rudiment, did it return to land, ever be again the land-limb once it was. On the other hand for its limb to develop into something utterly different, would be no unlikelihood. What had been for millions of years during a watery existence our apparatus for breathing has now nothing to do with breathing but serves our hearing in the air. Evolution can scrap but not revive. Doubtless the geneticist can say if this is so, and if so, why. The huge beasts whose size and weight are thought to have been their ruin could, one might suppose, have been saved by return to their less cumbrous ancestral types. But no, they were scrapped and other types brought on.

Obstacles to life's adventure we might have supposed insuperable were overcome. One of those old difficulties was that life at its beginning had been wholly aquatic, though so long ago that the very saltness of the sea was then much less than now. There the life in it, for instance that of our own primitive stock, multiplied,

flourished, and evolved. Later this life invaded the land. Some of our own early stock took part in that invasion. Life as chemistry, is so to say a dynamic 'steady-state.' The moving equilibrium of the cells' life in our early stock was almost literally an energy-eddy in the sea. The water of the sea conditioned it. Its energy-exchanges were based upon the sea. How if cut off from the sea could such a life exist? The Canadian biologist, Archibald Macallum, gave a reading of this riddle. The salts dissolved in our blood to-day commemorate it, in kind and in concentration. They are those of the ocean of that long past geological epoch. Already in that sea the vertebrate creature, with many of its cells buried in the body's bulk, away from actual touch with the sea-water, had evolved a system of branching tubes and a muscular pump, the heart, bringing to each buried cell a blood of salinity similar to that of the archaic sea, a substitute for that seawater in which its cells had first arisen. In this way the cells though buried away from actual contact with the sea still effectively retained their old habitat, to which their ways of life were adapted. The cell-mass forming the individual manufactured an internal medium, so to say, to substitute the sea. When it left the sea altogether for its Odyssey on and over land, it had but to carry that habit of manufacture with it. It has done so. With that it has crossed mountain ranges and desert sands carrying its own medium with it. It has invaded air as well as land. It runs, and flies, and walks erect. The water of ocean itself has changed from what in that old sea it was. It has changed with the washings of rivers into it for millions of years since then. But the blood, a dynamic equilibrium, has in respect to those salts remained steady. The poet sang, with more literal truth than perhaps he knew, invoking the sea, "the salt is lodged for ever in my blood." * Despite the vicissitudes of time the blood's salt still retains its likeness to the salt content of that archaic

* W. H. Davies.

ocean which our ancient ancestry forsook. That some of them did give up that old ocean allowed the possibility of our becoming what we are. What might have seemed to forbid at the very outset all approach to what we are, was ventured and overcome.

This strategy, by which life overcomes the obstacles of unfavourable environment—manufacturing a piece of environment suited to itself and carrying it about with it—Claude Bernard was the first to detect as a principle of strategy in the adaptation of the organism. Sir Joseph Barcroft has examined it anew, and has shown that it applies particularly to the maintaining, despite untoward circumstances, constancy of conditions for the brain. It is part of the basis on which we can rest our claim to be the most successful animal of the present period. An index of our success is our ability to dominate the external environment, and live efficiently under the stress of various adverse surrounds. That the human life conserves as it does through wide vicissitudes, climatic, etc. the normal activities of its mind, despite such threats (Barcroft), is an example of the polity of life as shaped in evolution.

The life of the cell is a moving equilibrium of a kind to which oxygen stands in special relation. An old phrase tells us that 'oxygen winds up the vital clock.' That clock needs continual rewinding. There is in the cell no large reserve or store of available oxygen. There is oxygen put away, but the continual need is for oxygen as cash. The free cell's surface, e.g. amoeba, is actually bathed by such oxygen as is in the field around it. The oxygen it needs lies at its door. It breathes it. But not so the cells when aggregated into the mass of a many-celled individual. Then some of them live many thousand cell widths removed from the nearest field-oxygen of the surround. Yet each and every cell requires supply from the field-oxygen, and also to rid itself of its own waste by casting this latter into the surround again. In the complex individual the field outside is quite remote from

the great mass of its internal cell-lives. Evolution when it produced the many-celled individual had to meet this difficulty.

There is a process, so characteristic an accompaniment of life, as to have been even from primitive times accepted as life's veriest symbol: the drawing of breath. The process has given picturesque words and phrases which in all languages stand for life: 'anima,' 'spirit,' 'breath of life' and so on. Science, when in due course it came, had nothing in the main to add to that primitive inference about the rhythmic sipping of air as being close to the very heart of life. The body took a draught of something invisible which fed life's flame. Science when it came did but resay in its own words this which had long been thought. So too it confirmed that at the end of the individual life there was the return of something, beyond vision, to the air as life's concluding act. Science added detail, and some amplification. It taught in what way the taking of breath took part in a commerce between air and life. It showed how it was that the moving of the breast was of urgent import to every speck of which the body is composed. It found the process not magical but chemical. Are its symbolism and its pathos any the less for that? Does to add deeper knowledge detract from its assessment in human values? It would be a strange scheme of human values which could think so.

We were looking at enzymes, and at the key-position they seem to hold in the chemistry of life. In this eminently vital process 'breathing,' enzymes play a key-rôle. They help us to it as chemistry. Our rhythmic breath renews air in the lung. The blood, as it flows through, can thus take up oxygen and transport it thence to all the parts that want it; and all parts do want it with greater or less urgency, and with particular urgency the brain. In the brain the draft on it is always quick. The body's internal mass not having direct access to the air, the blood brings to it and into it the oxygen from the air and puts it within reach of the cells, for them to take or

leave. The blood has no machinery compelling this factor of life, oxygen, into the cells. Its rôle is to offer to them a sufficiency whether they want more or whether they want less. This variability of need the blood stream, by broadening or quickening or both, meets with admirable flexibility. But each cell is arbiter of its own intake of oxygen. We remember that, microscopic though it is, each cell is a little self-centred life.

The secret of the cell's ability to take the oxygen offered it, is the presence among the chemical systems of the cell of a special enzyme-system. Many substances in the body, that is to say within the cells, do not readily oxidize with molecular oxygen at the temperature which obtains in the body; they are dysoxidizable. The respiratory enzyme in the cell can with molecular oxygen bring about rapid oxidation in the cell. There is present in a majority of cells a substance which throws in the spectroscope characteristic shadows; these shadows disappear on oxidation. In living cells watched with the spectroscope these shadows are seen disappearing and reappearing periodically (Keilin). Oxidation and deoxidation are going on. This is traceable to the respiratory enzyme. There is, it is said, only one part of the enzyme to 100 millions of the cell. None the less this 'breathing' is fundamental for the living of the cells. To interrupt it long ruins the cell beyond repair. Mercifully there are grades in the approach to that disaster. With the cells of the brain that kind of step is what the surgical anaesthetics are believed to proceed to. They hold up the breathing of the brain-cells and for the time being 'pain' is no more; still less intellect, memory, emotion. The mind is treated as a chemical process. And effectively so and as mercifully as effectively.

The catching up of oxygen into the spinning vortices of the cell is but one aspect of breathing. The other aspect is the relieving of the cell and the body of such energy-systems as are drained of all that is available in them for the body's use. These residues clog if they

remain. In this relief the moving blood acts as transport and sweeps the débris toward the field outside. It sweeps it to the lung; that is to the gateway to the air. But as the stream runs past that gateway the stay of each arriving particle is short. There would not be time enough for due escape through the gate were not the expulsion specially speeded up. The blood provides an enzyme which hastens the hydrolysis of the carbonic acid (Roughton). The carbonic acid breaks up into water and carbon dioxide, and this latter goes through the gateway and is exhaled. The efficiency of the means is remarkable. We all enjoy its advantage, though we accept it as a matter of course. When we are physically active, as for instance when we run, a volume of blood eight times the whole of that within the body may race through the lungs each minute. Thus we can exert ourselves effectively to the degree we do.

A property of cells which comes into play in the developing embryo is that they wield influences one on another which mere inspection of them would not guess, let alone discover. After the fertilized egg-cell's first division, each of the twin cells derived from it is the rudiment of one-half of the future creature (tadpole). But let the twin cells be separated without harming them and two whole tadpoles form. Each of the two cells produces then a whole creature instead of half a one. Evidently the twin cells in juxtaposition influence each other. Each restrains each so that each makes a half-creature coherent with, and mirror-picture of, the twin half. But left to itself makes a whole creature. There is reciprocal influence. So similarly, nerve-cells have certain special points of contact one with another. At these points one influences another. The one excites the other to specific action or restrains the other from specific action. From this reaction the nervous system becomes possible and develops its integrative action establishing the individual.

Evolution entails reconstruction. The fin which swims

reappears as the limb which walks, or the wing which flies. Not that what is a wing was ever a fin, but the rudiment now corresponding with a wing was potential once of a fin, not of a wing. In this transition the progress is often toward the more complex. It is as though a key to efficiency lay in complication. The human arm would seem, taken all in all, to be the most complex limb which evolution has produced; it is too we may think the most recently evolved limb. Perhaps it will lead to something more complex still. The human brain is the latest brain and it is the most complex. Increased nerve-management here seems to lead to more nerve-management still. New nerve is added to remanage old nerve. Fresh organization roofs over prior organization. Were it a business organization there would be criticism. Progress under evolution takes the direction of increased complexity of organization.

This is partly because progress may lie less in doing the few things better than in doing a multiplicity of things adequately. Thus J. Z. Young, writing of the nervous system, points to the greater complication of the honey-bee than of the worm. "Both can walk and eat, and the worm can swim and in some cases secrete a tube, but the bee can fly and collect nectar and pollen and make combs and stock them with honey, clean its limbs, dance to communicate with its fellows, warm or cool its hive, and sting an enemy." When a single specialization becomes highly effective for its purpose, it tends to become so inextricably entangled in the circumstances of a particular place and time that it can never be disentangled. That is, evolution can forget that places and times change, and that the surround is always becoming another surround. A specialization outlives its use. It can become a fatal encumbrance. The more general has to be returned to, as a starting-point for fresh departure. That is less difficult with a complexity which means diversity of doing.

The planet as it changes is continually putting an end

to types which it has made. It is continually scrapping old patterns which have served their day. Types which under a changed surrounding no longer sufficiently fit. It does not destroy them so much as lets them lapse. They are faults which eradicate themselves by being fatal; they amount to suicide. The natural history of Jean Fernel's time did not know this aspect of nature. Fossils gave the first hints of it. The mid-Victorian invocation to Darwinism, a decade before the 'Origin,' arraigning Nature, urged against her that

> From scarped cliff and quarried stone
> She cries a thousand types are gone;
> I care for nothing. All shall go!

And Nature destroys not only her old life-patterns but her new ones too. If by a mutation is meant inborn difference from the parent which starts so to say wilfully and perpetuates itself, such occurrences are frequent enough. Some cannot perpetuate themselves because the individual never ripens. There is a lethal mutation of the rat where death ensues from an anomaly of the cartilage, long before maturity.* In the series of breeding experiments on the fruit-fly *Drosophila*, carried out over a number of years, more than 300 different mutations have arisen. Many of these bring about the early death of the individual. They are modifications of pattern which prove unworkable, handicaps against the creature's living, sufficiently heavy to preclude the individual's completed existence. They are misadventures in the field of new design. Such are scrapped before they go any further. Wild Nature would be a harder school still for 'freak' designs. What chance of living would some of the kinds of dog seen in our dog-shows have if born in wild Nature? Nature would weed such out of its stock almost at their start, were it not for man's intervention. In the remodelling of her stock

* H. B. Fell and H. Grüneberg, *Proc. Roy. Soc.* B, cxxvii, 257.

Nature therefore lets some models lapse at once, while making and encouraging others.

And what shall we regard as progress? The naturalist is, as we know, accustomed when dealing with living things to speak of some forms of life as 'higher' some as 'lower.' It is a custom which extends far outside the naturalist. Indeed the naturalist is becoming more chary in his use of it than are the rest of us. He feels probably more than most of us one successful form of life is just as 'right' as another. To employ 'higher' and 'lower' seems in a manner to assume for ourselves the position of a judge as to what is best in this great universe. Our excuse may be that we are out to try to understand, and this appraisement is part of our attempt at understanding.

Setting aside the question of 'values,' the bare facts as far as we know them show an array of concrete lives much more than myriad-fold in type. They maintain themselves as such although individually possessed of but a short term of being, and although beset by circumstances many of which tend to their destruction. Each is in equilibrium for the time being with its surround. But it is a labile system. Its very weakness as a chemical composite is its strength biologically, its advantage for the uses of life. It trembles like an unimaginably sensitive spring, and its trembling is sympathetic with certain specific vibrations. But violence easily overwhelms it altogether. Judging by this frailty of the living systems which we know to-day we may imagine life at the beginning a hazardous and oft frustrated adventure. Those earliest 'living' systems would be local products of the spot developed from what was there. Perhaps to-day it would be a matter of discussion whether to call them alive or not. But once established as a beginning, 'life' has been extending its habitat ever since. Spreading in area, height, and depth, over the planet's side. It fits wherever we find it. Its fiercest competition commonly has been with other life. There are those forms of life which are termed 'parasitic.' The parasite lives on the body of

some other life which is its host. In some types of parasite the circumscribed environment within a part of its host provides all needs, and is all the parasite is adapted to. Its food being prepared for it by its host, all but its absorbent organs go. Apart from them it becomes a simple bag of genital products for reproduction of its kind. In its way it is a marvel of fitness for the existence it leads, and for reproducing its generations. Compared with forms of life which employ powers of locomotion which range continents or oceans, and finesse of behaviour which may outdo the utmost human ingenuity, the term ' higher ' in the latter case establishes its convenience by logical right. It we ask a test for which among living forms are ' higher,' range of dominance of the environment is one of the features to which the term ' higher ' can be accorded. Since mind is one of the great keys to dominance of the environment, ' higher ' in that sense in biology is almost graded by degree of mind. At the present time no range of domination of life's environment is so great as that of man. He is as regards conquest of his surround the most successful, at present, of all living forms. On that ground we can acclaim him the ' highest ' of all living forms.

Now that the production of new forms of life can be looked on as a manifestation of the working of purely natural processes, judgment stands freer in respect to it. We argue from it neither prescience nor regard for what in relation to human behaviour we call ' values.' It is well none the less to compare it with human standards of doing. Such comparison seems demanded. Uncritical admiration of Nature, whether inanimate or animate, has to be replaced by truer aesthetic and ethical evaluation. As to the former, much as has been written about Evolution, the aesthetic aspect of its products has as yet I think been barely touched on. That some relations in Nature and some concrete things in Nature have aesthetic appeal, affording unsurpassable delight to man,

is no less certain than that some others seem to him unsurpassedly hateful. In living Nature what we were noticing was that, from the point of view of success and fitness, it is the complicated which seems to be Nature's climax of rightness. The simple is at a discount. Whereas in aesthetics the simple may, I imagine, constitute the very climax of admirable achievement.

In some ways, it is as though evolution said, "Other forces can destroy; in so doing they clear my way. But I build, and I go on building." Evolution is a corollary to organic growth; the inorganic does not grow and does not exhibit evolution. We have heard that Nature thinks in mathematics or in geometry. Being what she is we may suppose her not more of one calling than another, seeing that she is all. But if we choose, looking around us terrestrially, to indulge our fancy and to think of her as excelling in some one way, it seems, on this planet, nowhere more evident than as chemistry. Of course, this may merely say "Man is beginning to know some chemistry." The subvisible structure of the living things which are evolution's material consists mainly of molecules of great complexity and size. Most of these are themselves products of evolution of life. That is, the very blocks with which evolution now builds it has largely itself evolved. Amending the term 'block,' which is too static, let us remember the living edifice is strangely watery. We think with surprise of ourselves as 80% water. It reminds us that the water in this evolving building is a field of action, an arena for the play of energy, more than an arena, a means and medium swarming with electrical charges; the water is no mere static cement but a busy scene, the market place of a chaffering population.

Among the acting systems which shape and dominate this field none are more important than are the proteins. These, even among the larger molecules, are giants. Each comprises a complex assembly of smaller but still considerable chemical groups. The proteins are aggre-

gates characteristic of and seemingly essential to life. No concrete life commonly accepted as life is without them. Protein kinds are hugely numerous. They form an immense chemical race. Moreover the theory of their type of construction indicates that, in almost inexpressible number, more varieties of them could exist than have been found.

Their upbuilding, down-pulling, and modification by reconstruction form a large share of the business of the living cell, in other words, of the business of life. We may ask how, broadly taken, does the cell do this. It would seem mainly by those transferrers of charged energy, catalysts. The changes of molecular constitution, reassortment of atoms, with concomitant redispositions of energy, seem to be worked step by step by catalysts, enzymes. The process of constructing a complex protein can be summarized perhaps as a sequence of many steps at each of which a simpler but yet complex state is by specific enzymes turned into one still more complex. It may be that the product itself carries within itself ability to catalyse its own growth further. The chain of steps can go on, until the protein formed is one which has not the specific enzyme for building any higher. The synthesis of the proteins, their composings and transformations, seems the work of specific protein-constructing enzymes. And the enzymes themselves appear to be proteins. It is a case of one part of the cell, one constituent of the cell, acting on another; if you will, one charged system in the cell acting on another also in the cell. We are reminded of Aristotle's "Part acts on part, as in an automaton"; and as so often in principle he was right. Matter working itself. Our Jean Fernel would add, under incorporeal direction.

An enzyme is a potent means to an end, but each particular end requires its particular enzyme. The chemistry of the living body were it not for enzymes would need conditions of heat and pressure and movement of violence such as would destroy the living stuff.

The enzyme is a specialized donator and acceptor of energy. It can be likened to a special channel along which energy can pour. The enzyme itself is not consumed in the action it favours. It lends a hand. A tiny structure, it is a rocking bridge that transmits and retilts for more. But it must fit at both ends. In every cell the enzyme-system of the cell is essential to the cell's living, which is to say, enzymes are essential to the living of the whole body throughout its every speck.

The smallest separate life known, the smallest concrete life, would seem to be the virus-particle. It is so small that in some instances the microscope has never yet been able to descry it. The so-called electron-microscope, which enlarges effectively about twelve times more, may pick it up as a 'blot.' The virus-particle ranges about the extreme of what the microscope, even when flooded with specially fine-grained light, can see. It is a great deal smaller than the smallest cell. It passes through the pores of a filter which keeps back the tiniest bacteria. It is so small as to be not much larger than some of those giants of the subvisible within the cell, the protein-molecules. The virus-particle cannot therefore embrace within it a great number of large molecules. Its life must be in so far reduced to the simple and at the same time to the very special. Extreme simplicity and extreme specialization often go, as we were saying, with parasitism. The virus-particle is parasitic on other life. It lives by turning the protein of its host into its own protein. That is to say, minute and minimal as it is, it yet lives by enzymes; again suggesting that the enzyme is ubiquitous in life.

The cell was discovered some two and a half centuries ago. But not until last century was attention drawn to a 'little area'—so its discoverer the botanist Robert Brown termed it—as constant feature inside every cell; a speck within a speck. This 'nucleus' is a nodal point in the cell's living. If the cell be torn into two parts, one containing the nucleus the other without it, that with

the nucleus, even though much the smaller, still goes on living and repairs itself. The other without the nucleus dies and disintegrates. Whenever in the course of growth the cell multiplies, the nucleus divides and one half of it belongs to each of the daughter cells. The nucleus is seen to initiate the division. Again, when two cells conjugate, the coming together of the two nuclei seems the step most important in the whole process. The details of the nuclear union are facts fundamental for the studies of the geneticist. The nucleus is too the cell's nutritional nodal point and centre. Its influence extends through the field of the cell right out to the cell's surface. That may not seem far since cells are small, but in molecular distances it is so.

A unit integrated of subunits seems always to meet sooner rather than later an upper limit of dimension. The atom would seem to say so and the organic molecule would seem to say so. It is so with the cell. With the cell the explanation of the limit is broadly clear. The cell is an integrated system which depends on upkeep of currents of energy through it. The medium for the energy-exchange of the cell with the surround is the interface between the cell and the surround, in short, the cell-surface. The quantity of the energy-exchange is, other things equal, a function of the cell-volume. For a cell approximately spherical a size-limit is soon set, because the volume increases as the cube but the cell-surface for interchange only as the square. The cell lives so as to say on its surface. A certain amount of cell must have a certain amount of surface, i.e. contact with the surround. A spherical cell if it becomes *large* possesses insufficient surface for the energy-exchange essential to its 'living.'

In some cases the cell, though microscopic in most directions, stretches in others to much greater than microscopic distances. It may be a thread even two feet in length, as in our nerves. Its end then is, microscopically speaking, immensely far from the nucleus,

molecularly speaking astronomically distant. Yet, to cut off the thread from the distant nuclear speck is to kill the whole thread; in a few hours the thread is dead, even to its farthest tip. But though the thread cut away from the nuclear part dies, the nuclear part not merely does nor die but proceeds to grow and generate a thread anew.

The cell is clearly a field of action dominated by its kernel, the nucleus. Its nucleus is a nodal point which unifies it. The cell's living field, including and owing to its nucleus, is integrated. Although the cell's life is manifold it lives as one. Its nucleus is a nest of enzymes. Fairy-like agents, they transform as did harlequin in the old pantomime. The house of life rises under their wands. It is the house beautiful or not according as we think, for nothing is but thinking makes it so; and *our* thoughts are the only such thoughts about it. Beauty is a lonely thought, for human consumption solely. Life's house, built as it is, is at least a house of health. A house of *joie de vivre*. Though at times the ferment-tribe may turn aside from health and build a cancer. Then the house can be a house of pain. Could our sixteenth-century physician with his curiosity and earnestness, after he had disabused himself as he did of the influences of the stars on humanity, have peered into the subvisible within the cell, the intracellular enzymes might have afforded him something of that wherein the stars had failed him.

The nucleus is a nest of enzymes, and is par excellence the organ of heredity. Apart from those times of cell-convulsion when the cell multiplies by tearing itself in two, the nucleus is a tiny ball cleanly limited from the rest of the cell by a membrane. Outside it the mass of the cell, although semi-fluid, is far from being a featureless jelly. Rather it is a many-chambered gobbet of foam. Its chambers and tunnels are the scene of many chemical operations. Its framework is no rigid one, but a shifting labyrinth of dissolving walls and floors which

form, melt and reform as the work of the chemical factory requires. Somewhere in it reigns the nucleus with a surface-sheet of its own, a special assembly of enzymes. To it the moving contents circulating in the cell have recurrent access. One view of what happens holds that the enzymes bearing a weak electrical charge combine, if of suitable spatial pattern, with the cell-contents of opposite charge moving toward them. The combined product, with some residual charge still left, then combines with a next-comer charged oppositely to itself, if of suitable pattern. The charges satisfied the neutral molecule drifts off leaving the nuclear enzyme free to repeat its work. And so on, cycle after cycle. A single secreting cell can, it is calculated, produce and pour from itself a thousand enzyme-containing particles in every second.

When the cell reproduces itself that internal convulsion of the cell, which ends in rending it, is heralded by contortions of the nucleus. The nucleur membrane as such vanishes. The technique of this study employs dyes; the colourable part of the nucleus, which is the enzyme part, reshapes as short rods easily seen, the chromosomes. The chromosome is an organ concerned in the hereditary transmission of bodily and, as would seem, mental characters. These characters are transmitted in groups. Each chromosome carries a whole set of characters. The characters belonging to the set of one and the same chromosome are said to be 'linked,' because they are transmitted together. Occasionally the linked characters are not transmitted all of them together. Observed behaviour of the chromosomes accounts for this. Thus it is that such a character as blue eye or fair hair can be identified with the adventures in the body of a particular microscopic point. At fertilization the separate chromosomes of the two parent-cells combine in pairs. Each chromosome in the one parent-cell meets the corresponding chromosome of the other parent. The chromosomes are thread-like and in their coming together

they may get twisted across each other. Then when the fertilized cell tears itself in two, each chromosome—and each is now by-parental—splits lengthwise, and gives one half to each of the two new cells. In this splitting if the chromosome-thread is twisted one part of one may get exchanged for a corresponding part of the other. Then two traits, commonly partners, are reshuffled. And there are several other ways of shuffling, to extent often not manifest, some traits lying submerged; thus a blue-eyed baby may come to a pair of dark-eyed parents. Traits can thus be identified with particular points in the nuclear thread. As we saw there will be a protein for the hair of a man, a somewhat different one for the hair of the dog, another for the hair of sheep and so on. Further, individually within the species heredity hands down in one man enzymes which bring forth from his food dark hair, in another man enzymes which from similar food bring forth red hair.

The particular point in the chromosome-thread which does this or does that, which is in short identified with potentiality for making an adult trait, is called a 'gene.' It carries an enzyme-system, the enzyme-system for the trait in question. The solving of the riddle of heredity is, we may think, a business for the chemist. To-day I fancy no geneticist questions but that the inherited unit-character awaits chemical definition. For instance the Mendelian chlorophyl-defect runs with a specific lack of catalase. William Harvey's epigenesis promises to be in the main an affair of catalysts. The point I would keep in mind here however is that the story of hereditary development seems to us to-day to be a chemical story. The romance to which evolution keeps adding new chapters is therefore in the main a tale of chemistry.

Heredity deals with us as though we, whether he or she, are patchworks of characters, and as though in dealing these out to the individual they can be, to some extent, shuffled. Observation finds that in that phase when the life of each of us is held within the compass of

a single microscopic cell these characters, in potentiality, lie as a row of points along the length of the nuclear thread. In the little fruit-fly, *Drosophila*, some 2500 such points have been identified and mapped. The mapping has been tested by bombarding one or other point by destructive X-rays. The trait in question is then found to suffer. Our blue eyes, fair hair, and so on are a row of points set out along the nucleus of that one cell which we then are, a row of genes. And the gene? A protein system containing auto-catalysts? A system which within the cell is continued and replenished ultimately from the world outside. The original system of a gene must become millions as the human embryo grows. Yet, at each step, relation to the future trait is preserved, nurture attending as a genius, kind or evil. Among the essential dynamic properties of the chromosomal gene are its catalytic capacity for specific reproduction and the automatic regulation of that capacity. One might think the process would beggar the variants possible even in protein-kind. A little arithmetic relieves that apprehension. Even with only thirty amino-acids to ring the changes, different proteins are possible to a number requiring twenty-three ciphers after the third figure. Set out in numerals it would run across half the width of this page.

Our glimpse of this scene of armies of microscopic agents engaged, swiftly and as if preconcertedly, yet unfeverishly, building a new individual to a plan ripened through countless ages, leaves us with the inference that chemistry holds the key to its comprehension. An ingenious writer has described it as implying a subconscious memory in those millions of cells which perform it. An unconscious memory innately stamped upon the behaviour of each cell in the successive generations which enact it. Our critic, the materialist, would not be moved by such an ingenuity of view. There is nothing to show, he might say, that each phase is not the necessary chemical successor to the next preceding. He finds

it a subject where mere ingenuity is out of place. Each modification which the action undergoes in its progress is one which a change in the chemical circumstances makes not only possible but obligatory.

But we may ask does not evolution apply to mind as well as to the body? How then does chemistry come in? The 'how' between mental action and chemical action is still to seek. There is none the less a 100% correlation as regards 'place' and 'time' between finite mind and chemical action in the brain. The equivocality of that 'how' should not, I think, disturb larger facts. Evolution of the mind is as incontestable as evolution of the body. Heredity appears in mental traits as in bodily. It would seem that consentaneously evolution has treated body and mind together. It has envisaged them as complemental features of that which it handles as a concrete unity, the σύνολον of Aristotle, the individual, which we might even style the concrete persona. Evolution speaks to us in the same breath of body and of mind.

We saw how our bodily life carries with it its own evidence that its origin is terrestrial. If we employ exotic to mean of non-terrestrial provenance, there is no ingredient in bodily life which is exotic. Its chemical elements are among those commonest on our planet. Its whole is redolent of Earth, whence it was dug. Even likewise with finite mind. Its ways affirm it to be so. Its history proclaims it to be so. Our stock is the vertebrate stock; our body is the vertebrate body; our mind is the vertebrate mind. If the vertebrates be a product of the planet, our mind is a product of the planet. Its activities and proclivities declare it so. Its senses each and all gear into the ways and means of our planet which is its planet. They are adapted to it, as a fish's body to water. Its senses fit the physical constants of the planet's side. Its so-called 'heat' and 'cold' take the body's point of view of temperatures which obtain here. Either side of their narrow range of 'heat' and 'cold,'

where temperature contains a threat to life, they pass over into pain. Ours is an earthly mind which fits our earthly body. It produces percepts of earthly things from an earthly view-point. It helps the besouled body to deal with terrestrial things, thereby to live. Our mind constructs 'time' and its time's rate is that of its besouled body's terrestrial habitat; although itself, not unnaturally, has supposed it to be an universal and absolute Time. The last preceding turn of its own planet is its 'yesterday,' and the next expected turn will be its 'to-morrow,' and the notation of both is taken so that it may exploit that planet the better.

"Death and his brother Sleep." In death we are proverbially one with our earth. As to sleep, is there anything in sleep which frees us from earth? Dream? A disorder of earthly fancies—thinking adrift from judgment, so even the better betraying the currents of mortality. Freud saw there an opportunity and seized it. In his hands it proved a key to the reading of earthly misadventures. Then, waking? Is our waking a change from the earthly to the unearthly? Does not waking conjoin us yet more coherently with earth? When our mind truants from an everyday path by means of 'fancy' it still is wholly earth-bound. It may try to break away from our native inescapable soil, but it cannot.

Our imagination in medieval times was greatly in earnest about the Evil One and transmundane demons. Yet its vision could achieve nothing to the purpose beyond contriving ugly hybrids from familiar shapes of terrestrial creation. When Dante's noble imagination travelled the Inferno, Purgatory and Paradise it still walked Italy, the Italy it loved and grieved for. Again that fancied *anima mundi* of Plato is wholly a terrestrial fancy. Or if we, accrediting the soul with unearthliness, prefer to entertain the supposition that there is more chance for its unearthliness to show in mediumistic revelation, we have, type of that class, Hélène Smith *

* Th. Flournoy, *Des Indes à la Planète Mars.*

and her trance-experiences of the planet Mars and its inhabitants. Nor then was it purely that the words of the medium defeated that extra-mundane scope, because, of necessity, earthly words. Her pictorial representation, automatically produced, of Martian persons, houses, landscapes, plants and insects remained terrestrial, save for a little topsy-turvydom of the Alice-in-Wonderland sort, though not so entertaining. The imagination of the medium during trance, instead of revealing unearthliness, is earth-bound with a banality that the literary imagination does not suffer.

"Many," says Socrates, "are willing to go to the other world from the hope of seeing there an earthly love, or wife or son and conversing with them." Conversationalist as he was, he tells us that for himself 'an infinite delight' of that world will be to converse with Odysseus and the leader of the Trojan expedition. To imagine paradise a lofty mind thus invokes its favourite pursuit from earth and a custom of earth's social creature, man. Mind's earthliness innately shapes all it does, perhaps most so when it tries to be unearthly. Let us not disown mother Earth; rather let us rejoice to call her 'mother.' Earth's nature is our nature. We owe to earth the entire gamut of our mind's wonders, whether of joy or pain. Life's story has been an unfolding of germinal powers of the planet bringing emergence of mind. Let us give thanks where thanks are due. We are, in biological phrase, reactions. The situation creates the life which fits it. The dry land created the feet which walk it. Our situation has created the mind which deals with it. It is an earthly situation. Along with the sea it has created in us the wonder of the sea. The situation engenders the reaction to it. If the agent is terrestrial and the reaction is terrestrial is not the medium of the reaction terrestrial? The medium is the mind.

This might well seem obvious. It cannot always have been so, for there have been other views. Our mind wondering about itself has at times indulged the thought

that it is not earthly. It has judged itself to be of 'heavenly' origin. It has so judged sometimes apart from any special revelation of faith. Therefore it is that such a view comes before us here.

The soul, when Omar Khayyám had sent it on its great excursion, returned with answer "I myself am Heaven and Hell." The Θεός of Aristotle seems in its kind the least earthly and the least anthropomorphic of such conceptions ever drawn. So detached and impersonal does it stand that we can feel it would as observer be the one observer no invalidation by a 'principle of uncertainty' or Niels Bohr's 'principle of complementarity' would limit. As conceived by Aristotle it is the one observer free from reaction with the observed.

A world of our imagining is a world of earthly experiences reshuffled and repieced. The uglinesses of our finite mind are terrestrial uglinesses, e.g. cruelty and egotism; its worthiness is terrestrial worthiness, e.g. prudence and resource; its climax of worthiness, altruistic love, is a sublimation of earthly nature's love. Our mind is part and parcel of terrestrial nature, in which it is immersed, and there and only there can it meet with requitals and fulfilments.

What can it point to unearthly in its nature? What has led it to regard itself as not of earth? What signs of unearthliness attach to it? Its own experience is the entire gamut of its knowledge; if evidence of this alleged unearthliness is anywhere it must exist there. We would ask to hear what it is. Our sixteenth-century Jean Fernel held, though he opposed astrology, that our mind is no terrestrial product but derives its nature from the stars. To others again it has seemed even wholly praeternatural. But of that derivation mind and nature themselves supply little confirmation. The naturalist tells us of the finite mind that, as recognizable mind, it has a certain well-defined distribution in nature and is never met with apart from a body, which latter is in no wise praeternatural; and he finds that the mind corresponds functionally with that

body. This very correspondence with its body has however been declared a supernatural and miraculous feature. Such a problem does not present itself for those who do not regard the individual, for instance the individual man, as presenting phenomena belonging to other than a single category. For instance, if the mind as well as the body be regarded as some form of energy, the fact that mind and body co-operate follows from their being parts of one homogeneous system. That as the ages pass they change in correlated fashion under the genetic process and environmental stress is but in accord with their being interrelated parts of one and the same system, as on this view by assumption they are.

But if the two are regarded as not of one category then to explain the working agreement between them a 'pre-established harmony' miraculously established at outset has been invoked. Precurrent supernatural intervention is called in to 'explain,' for example, that the various and different species of bodies embodying finite minds always tally with their specific bodies. The ox-mind in agreement with the ox-body, the tiger-mind with the tiger-body, the monkey-mind with its body, and man's mind with his. The problem can however be treated as a local problem of the planet's side; it can be satisfied by natural processes. There is the fact that finite mind is always observed to be an embodied mind. The body is observed to carry with it the reproduction of the specific finite mind characteristic of that body. The individual breeds true, as is said, and that fact, despite the claim made for the finite mind that it is praeternatural, includes along with the concrete body the finite mind. That is, they both are in the hands of evolution. That they both are so, means that the tally between them in the individual is somewhat that of two malleable stuffs hammered into shape together at the same time between the same hammer and anvil. For each the adjustment so enforced by evolution is adjustment to a surround which evolution envisages, so to say, as one single surround, i.e. for

both body and mind. Survival has been the acid test for both. Under evolution the entry of mind upon our planet's scene we read as a further opportunity for fitting life to its surround. "Mind," says one of Shakespeare's characters, "is the slave of life." Mind's errand to life does bear that guise. It is one 'slave of life' the more. It marks a further means to 'life's' exploitation of the planet's side. Mind became one more tool for life and one more condition amid which life worked. The world became 'object' of it as 'subject.' An image of the world with which it has dealing, this terrestrial world, was flogged into its very substance by suffering as well as by reward. Its innate urge went out toward some things and not toward others. The key of its reaction to them was their use to the 'life' it served. The suitable reaction is often attained painfully; the unsuitable was weeded out of it by bitter experience. Even after the suitable of the particular case had been attained, that was not necessarily the end; the world still changed; what suited once had to be modified. 'Surround' would change and the corresponding life would have to change. Yet, for this finite mind through all as by some spell, its own life, even at worst of times, remained precious to it. Its striving after adjustment with its world was never relinquished, however dire the struggle and experience.

But 'pre-established harmony'! And by miraculous intervention! Conforming of the finite mind with its body's strife emerges in case after case as a hard-gotten gain won from a long running fight with adversity and maladjustment. It has been an outcome in the main of conflict where the nemesis of failure was perdition. Our world we recognize to-day as a world in making, and ourselves as a part of it likewise in the course of making. Our present is not only not static, its very motion is a motion which will to-morrow not repeat to-day. Our planetary islet is unfinished even as those island universes which the astronomer tells us are at various stages of becoming. Kant seemed to assume the human mind to be a finished

thing, a completed item of existence. But the huma mind is part of a tide of change which, in its instance, has been latterly and, we may think, still is, running like a mill-race. Living things are all the time busy becoming something other than what they are. And this, our mind, with the rest. It is being made along with our planet's making. We do not know that it ever will be finished. We see it as a provisional *ad hoc* arrangement of the present. Often will it be reminded of this when prosecuting its latest task of establishing the 'values.'

Fernel, could he be with us to-day, would perhaps see in evolution a triumphant instance of a train of 'purposive causation.' That the train of successive steps led in a definite direction does not necessarily presuppose it set out with a goal in view. The serial steps as looked back at from the latest one of them can appear as though the previous steps were directed toward reaching that, the latest one. Particles swarming round the nucleus in a cell are substrate for an enzyme-series. The product will depend on the substrate and the array of enzymes. It is our anthropism which as to that series regards one enzyme as 'preparing' for another? A gene would seem to be an heritable substance capable of autolytic increase by assimilation of the substrate. We do but anthropize it out of all recognition if we imbue it with an ideal and an 'aim.'

One doctrine (Driesch) taking from Aristotle the word entelechy—and warping his use of it—declares the gene a tool in the hands of entelechies, for the set purpose of building 'form.' With that we have a retrogression to mediaevalism. Jean Fernel left entelechy as he had found it,* a perfection material in nature. Bosanquet † remarked justly "the attempt to treat entelechy as a element operating *ab extra* upon the material syster when it simply represents the latter in its normal fun tion, must be held purely artificial and fictitious."

* Fernel, *Dialog.* i, 3.
† B. Bosanquet, *The Individual*, p. 193.

Guy Patin, old admirer of Fernel, scribbling in the next century one of his characteristic letters, wrote, "the Rabbis teach how God reserves to Himself three keys, one fore-knowledge of the weather, one fore-knowledge of our fate, and one of the mystery of life's reproduction. And three fine secrets they are. They are well kept!" As to the last one, life's reproduction, if our materialist, in his old frame of mind, to-day submit that he holds the key to it, he can, we may think, go into Court with a good case.

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PROGRESS?

IS human progress a reality or an optimistic dream? This question is still a subject of controversy, but amid all the differences of opinion there is unquestionably one direction in which humanity has progressed. Knowledge has grown—knowledge of the universe, of the evolution of ife and intelligence, of the history and nature of man. And the advance in understanding has been accompanied by progress in the systematization of knowledge and in the rational testing of facts and theories and speculations to discover truth and expose error.

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